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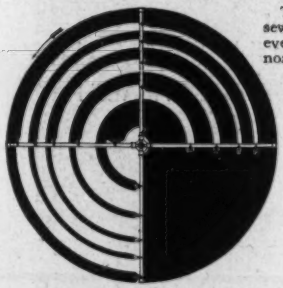

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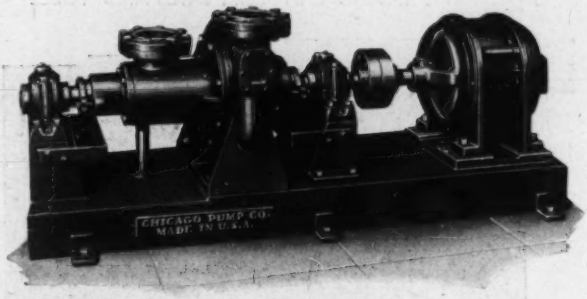

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Sewage Research

Research in Sewage Chemistry and Sewage Treatment. A Critical Review of the Literature of 1932*

By J. W. Bugbee, W. S. Mahlie, W. Rudolfs, Abel Wolman and Earle B. Phelps, *Chairman*

Committee on Research, Federation of Sewage Works Association

Chemistry and Biology

Studies of sewage per se have continued to be somewhat limited in attack. Aside from investigations devoted to individual aspects of the sewage complex, few fundamental data appear. Indole and skatole, both well-known constituents of sewage have been carefully identified and effectively removed by oxidation devices.[1] In Amsterdam, Smit[2] has determined the amounts of sugar present in sewages during the day time. As one might suspect, the quantities vary with the habits of the population. They reach as high as 80 p. p. m. and decompose rapidly. They were far below the amounts, however, which could be tolerated in the activated-sludge process and therefore the results indicate that the "sugar" explanation of bulking in activated sludge may not hold for normal sewages.

That the carbohydrate solutions may be quite rapidly oxidized biochemically has been demonstrated by Jenkins[3] in a series of small tray filters where sucrose acetic acid and lactic acid were readily converted by a mixed microbial population, even when the carbon-nitrogen ratio was as high as 80 to 1. Ammonia oxidation was most rapid in the lower part of the filter, where the concentration of sugars was the least. The results conform with those already published by Levine and his co-workers.

Bacteriophage in sewage has lost somewhat of its popularity as a subject for investigation. No material progress has been made in this work since the early reports of Arloing and Sempe. Practically all waters containing fecal pollution have shown bacteriophage,[4] but little else seems to be known regarding its activities. Much fundamental work in this direction has been carried out by Smit, in connection with the effect of sedimentation, light, temperature, chemical composition of the water and competition between the action of bacteriophages and protozoa on pathogenic organisms.[5]

As in the past, many of the official analytical methods for sewages and trade wastes stand in need of improvement. Foote and Nichols[1] have found, in general, that wastes with a pH value below 7.4 yield less free

* *Received June 8, 1933.*

ammonia than if the pH is maintained at this value by the use of a phosphate buffer solution. At high pH values, 10.6 to 11.6, the so-called free-ammonia increases. It is still doubtful whether even the smaller quantities of ammonia regarded by these authors give true indication of the amounts of free ammonia present in the sewage and wastes.

The determination of biochemical oxygen demand continues to be the most popular field for investigation in analytical methods. Bach[6] claims that higher dilutions of sewage and trade wastes give higher biochemical oxygen demand results. Although it is probably true that the most accurate B. O. D. value is obtainable only when dilution is unnecessary, a simple usable method for such a determination is not yet available. An adequate number of dilutions and calculations, as recommended in the 1932 Standard Methods of Water and Sewage Analyses, should result in a reasonably true picture of biochemical oxygen demand. As heretofore, the comprehensive laboratory studies performed by Theriault and subsequently abstracted in the report of the Committee of the Great Lakes States[7] have supplied the basis of our present procedure.

Some light has also been shed on the mechanism of the B. O. D. determination by Sierp and Fransemeir[8] in their comparative studies of the different B. O. D. procedures. They find no direct relation between B. O. D. and carbon content, using the direct oxygen method.

In a similar fashion, the report on the determination of dissolved oxygen by the Winkler method prepared by Theriault, *et al.*,[9] standardizes the method sufficiently for accurate results. The determination of carbon in solution in sewage and effluents is still in need of vigorous laboratory review, although the procedure developed by Bach[10] gives more consistent results than those obtainable from methods formerly in use in this country.

Sludge

Sludge digestion, handling and disposal continue to be one of the most popular fields for investigation. Paper after paper flows from the press, all adding valuable data to the already abundant literature on the most critical problem in the sewage treatment field. Basic studies as well as plant operation data abound. Some of the more hardy optimists in the sewage treatment field envision new, simpler and cheaper methods of avoiding this bugaboo of sewage treatment.

This interest in sludge digestion is international, excellent work being produced in Germany, England, Holland and this country. From evidence currently available, the reduction of solids in sludge digestion varies from 20 to 50 per cent, some of which is probably due to decantation. Sludge concentration is increased from 50 to 100 per cent depending upon length of time of storage and original moisture content. Most of the results re-

ported show an inodorous final product, which does or does not drain satisfactorily. The causes for the latter differences are still obscure.

One of the most elaborate reports of recent date on sludge digestion was prepared by a Committee of the American Society of Civil Engineers. Unfortunately, only a brief abstract of its findings[11] has appeared. The full report is in the Engineering Library in New York and can be consulted by comparatively few people. Several new separate sludge digestion plants have been placed in operation during the year, but the papers written by Taylor[12] present perhaps the most accessible operating results.

The heat and energy relations in the digestion of sewage solids have been most thoroughly reviewed by Fair and Moore,[13] with the establishment of empirical equations setting forth the course of digestion and the relationship between fuel value and loss on ignition.

The influence of temperature upon the rate of digestion could be quantitatively evaluated by their studies. For temperatures between 77° and 104°, the value of the temperature coefficient was twice as great for activated sludge as for fresh solids, indicating that temperature affects the digestion of activated sludge to a greater degree than it does the digestion of fresh solids.

These same authors[14] have studied the fuel value and the volatile matter of fresh and digested sludge, from which they conclude that the fuel value of the sludge varies roughly as the 4/3rds power of the volatile matter content. Their experiments disclose that the course of sludge digestion as measured by gas evolution could be formulated as an auto-catalytic monomolecular reaction, conforming roughly to the equation presented by Arrhenius some years ago for general chemical reactions. The yield of gas varied as the first power of temperature.

The recovery of gas is still being measured with considerable care as illustrated by the fact that Buswell and Boruff[15] show a possible recovery of 111 to 154 per cent of the weight of the pure substances digested, indicating that during digestion water acts as an oxidizing-reducing agent with some gas produced from the water during digestion. Partial confirmation of the data is supplied by Rudolfs[16] in the recovery of from 91 to 103 per cent by weight of the volatile matter decomposed. Mohlman[17] suggests more complete studies of these relationships before accepting the conclusion that a considerable amount of gas is produced from water in sludge digestion tanks.

From the standpoint of practice, the amount of gas produced per unit of sludge is one of the elements on which most information is sought. In a separate digestion tank heated to 73° F., Fries[18] reports a yield of 0.56 cubic feet per capita. Husman[19] arrives at a similar figure as the average for three years with an average temperature of 51° F. and sludge circulation. The gas yield to be expected from domestic sewage sludge under

practical conditions of operation, according to Rudolfs,[20] would vary from 0.6 to 0.75 cubic feet per capita per day. On the basis of volatile matter this would give a maximum yield varying from 8 to 11½ cubic feet per pound. At Decatur, Illinois,[21] the gas production from the Imhoff tanks has varied from 4½ to 6½ cubic feet per pound of dry solids. The production, however, on the mixture of sewage, activated and humus sludge has varied from 3.3 to 5.7 cubic feet per pound of dry solids. The average temperature of the tanks under these conditions was about 74° F.

These findings are generally confirmed in the data resulting from the summary of digester operation of ten plants, comprising 16 digesters, recently prepared by the Dorr Company. Their field results, summarized in 1932 and unpublished, show that these plants produced on the average 1.0 cubic foot of gas per capita per day, with three of the plants out of the ten receiving cannery or other trade wastes. In eight plants from which data were available, 17.3 cubic feet of gas were produced per pound of volatile matter destroyed per day. The solid contents per capita in three of these plants were above the average and resulted in gas productions of 1.29, 1.42 and 1.24 cubic feet per capita per day.

The gas analyses of these various plants showed variations in B. T. U. value from 620 to 710, with an average of 656.

The temperature of digestion varied from 69 to 90 with an average of 80° F.

Considerable interest has been aroused, of course, in recent years in the effect of various materials on the digestion of sewage solids. Gases have little or no effect on methane production,[22] while alum compounds apparently retard digestion and produce less gas, and iron contents give some indication of helping digestion.[23] The sulphate salts naturally produce more hydrogen sulphide, but retard digestion and consequently the rate of gas production. Trade wastes containing sulphates other than iron sulphates are probably detrimental to efficient plant operation.[24]

Industrial wastes, from the meager evidence so far available, result in lowered gas production when too large quantities are in the sewage. With proper regulation, however, as was demonstrated by Kessener as early as 1911 and 1912, and as confirmed by Eldridge and Mallmann,[25] sludge from straw board waste mixed with sewage solids may be adequately used for gas production.

In spite of the general interest in digestion at temperatures higher than 85° F., little progress has been made in thermophilic digestion during the past year. Ardern and Lockett[26] obtained interesting results with domestic sewage and with sewage containing trade wastes. Detailed laboratory investigation has proceeded on the same subject, without plant scale findings, however, being made available at this date.[27]

Special attention should be called to the examinations made by Downes[28]

of the iron heating coils after 3½ years of service in the Plainfield, N. J., tanks. They showed a crust about ⅜-inch thick on the hot end of the coil, tapering off to zero about two-thirds of the distance around the coil. The amount of the incrustation was not great enough to interfere with efficient heating.

At Essen Rellinghausen,[29] the sludge has been heated by the addition of hot water to 73° F., consuming about ⅓ of the total gas produced in the process.

Some quantitative study has been given to the heat losses from digestion tanks, and Rudolfs and Miles[30] conclude that the rate of cooling of sludge in air is directly proportional to the difference in temperature between sludge and the surrounding air. Muller[31] reports a heat loss of 6.7 B. T. U. per cubic foot of sludge tank volume per day in the operation of a sludge digestion tank in Halle.

Renewed emphasis has been given to the use of sludge digestion gas for pumps, air blowers and machinery, in addition to those uses most generally adopted for heating purposes. This valuable source of energy for driving power is emphasized once again in detail by Walraven.[32]

An understanding of the changes taking place during digestion, essential to a knowledge of gas production, sludge drying, odor nuisance, etc., is being supplemented gradually by the studies of Althausen and Buswell,[33] who have been interested particularly in the drying abilities of various sludges. Practical conclusions, however, are still far from the mark. Basic studies of the kind here noted and of the reviews prepared by Mills[34] on the colloids present in sewage are important for the future.

Under proper operating conditions, normal digester overflow liquor should not contain more than from 0.2 to 0.3 per cent of total solids or about 75 to 100 p. p. m. of suspended solids. In general, the return of such overflows to the raw sewage for subsequent treatment creates no ill effect, since on an average domestic sewage the volume of overflow liquor will vary from 0.07 to 0.15 per cent of the total sewage flow.[35] In some instances, treatment on sand beds or coagulation preliminary to subsequent treatment may be found to be desirable.

Practical digestion of screenings on a large scale has not yet been consummated. Small scale experiments have been reported, including the patenting of a special type of tank for the digestion of fibrous material.[36] Bar screenings mixed with tank skimmings have been digested on a small scale under careful operating conditions.[37] At the moment, however, the process of digesting screenings may be considered to be in an experimental stage.

Experimental addition of various types of enzymes to stimulate or control sludge digestion have not borne material practical fruit.[38]

A recent excellent summary of the factors involved in the treatment of

sewage sludge by bacterial digestion was prepared by Whitehead and O'Shaughnessy[39] in England. They emphasize once more that the major factors influencing the course of the digestion of sludge are water content, temperature and degree of alkalinity (pH value). The paper, with the discussions, represents a document of almost 100 printed pages and should be reviewed in detail by any one interested in the sludge disposal problem. It is comprehensive in scope and impressive in content.

Filtration

No important progress has been made in either theory or application with respect to sewage filtration processes. Limited studies have been made on various aspects of the filtration of sewage which have added somewhat to our understanding of the process, without modifying to any considerable degree the procedures as already in use.

Interest in the biological changes taking place in filters still persists. Observations on these changes in filtering beet sugar waste effluent have been reported by Calvert,[40] confirming the fact that certain types of protozoa, with sucrose solution, were prevalent in the upper sections of the filter while others persisted in the lower. The lower section forms apparrently require an environment relatively free from soluble organic compounds and they feed on debris, small organisms and bacteria. The results are analogous to those found in the filtration of settled domestic sewage.

An interesting effort by Ormsby,[41] working on so-called open and closed trickling filters at Pennsylvania State College, Pennsylvania, demonstrated the feeding of certain protozoa on bacteria. The findings are scientifically helpful, but their practical import remains to be demonstrated.

The survival of protozoa is regulated to a considerable degree by the oxygen deficiency of the water, with the result that they are able to reduce their metabolic activities to a minimum and survive until more favorable conditions recur.[42]

Practical changes in filter units have been few. With the exception of the plants at Pontiac, Michigan, built about fifteen years ago, and Springfield, Mo., a few years later, no mechanical distributors for trickling filters have been installed in large plants in this country. Renewed interest in the mechanical devices, however, has resulted in several small installations such as at Wilmington, Delaware, Lisbon, New York, and Escanaba, Michigan.

Preliminary bio-flocculation of sewage with activated sludge has not made as much progress as previous discussions seemed to predict. Birmingham, England, however, has had considerable success with its plant and its application has resulted in the elimination of the filter fly nuisance, the doubling of the rate of application of sewage to the trickling filters and the prevention of trickling filter odors.[43]

The destruction of the filter fly has had the further attention of a number of English investigators, and Scouller and co-workers[44,45] have found that a mixture of creosote and orthodichlorobenzine, at the rate of one gallon per 175 square yards, was sufficient to prevent the flies from becoming a nuisance for nearly a month. The cost of this treatment was $250 per acre filter per year. Experience at Plainfield, New Jersey, in 1926, however, with similar materials, showed much larger quantities necessary for good results.

Some studies analogous to that of filtration deserve mention at this point. These were concerned with the study of the distribution of pollution in ground water made by Dappert,[46] Sanitary Engineer of the New York State Department of Health, in connection with a suit by certain property owners of Rock Valley Center on the south shore of Long Island, alleging pollution of a natural water course through underground seepage from the percolating beds of the Rock Valley Center sewage treatment plant.

The sewage flow of about 1.2 million gallons per day is treated in a modern and well managed activated-sludge plant, the effluent passing to 5 acres of natural sand beds through which it percolates to the underground waters. At a point about 1500 feet away a natural spring of large flow forms the head of a small creek which, after flowing through several artificial ponds, empties into Long Island Sound. The investigation involved the sinking of some 43 experimental wells so located as to develop the course of the underground seepage and a careful examination chemically and biologically of the waters from these wells. The path of the sewage effluent was quite sharply delimited and traced to the natural spring referred to. The flow was through fine sand throughout. Along the course of this somewhat meandering path there was remarkably little dilution of the sewage effluent as indicated by the chloride content of 38 parts per million in the percolation beds and 33 parts at the spring. The most interesting result obtained, however, was the practical absence of bacterial evidence of pollution along a line of the flow of this seepage even as near as 400 feet from the percolation beds. At 1000 feet distance, total bacteria, 37°, were 2 per cc. as compared with 10,000 on the percolation beds, while *B. coli* were absent in 10 cc. quantities as compared with present in 0.001 cc. on the beds. Free ammonia on the other hand was oxidized only to the extent of about 25 per cent of that contained in the beds. It was concluded that the only nuisance resulting from the existing situation was the possible increase in algae encouraged by the presence of ammonia and nitrate in the underground waters.

Chlorination

The use of chlorine in the sewage treatment field continues to offer many opportunities for study. Its place in primary disinfection in sewage has

been well defined, but its usefulness in many other directions is still pursued with remarkably excellent results.

Obviously the reduction of B. O. D. by chlorination is one of the most important aspects of this problem. Enslow[47] has recently admirably summed up this phase. The evidence is gradually piling up pointing toward the production of chlorinated products non-assimilable by bacteria, which may at times be definitely toxic. Reductions in B. O. D. on settled sewage may amount to 25 to 30 per cent, with similar results frequently obtainable on crude sewage. Most significant in these findings is the fact that the reduction in B. O. D. may amount to as much as nine times that to be anticipated by the stoichiometric relations between chlorine and oxygen.

Carpenter discussing the Enslow findings reported on the results of some experiments on the Jamaica, New York City, outfall. The B. O. D. of this sewage averaged about 80 and the chlorine demand about 6 p. p. m. Applications of chlorine sufficient to give a five minute residual produced an apparent B. O. D. reduction from 77 to 32 p. p. m. or nearly 60 per cent.

Confirmation of these findings with a somewhat different theoretical explanation was further recorded by Hale in discussion of the Enslow paper from the results of analyses of sewage filter effluents in which a loss of albuminoid ammonia was recorded following chlorination. The loss corresponded to the reaction

$$3Cl_2 + 2NH_3 = N_2 + 6HCl$$

This destruction of amino bodies would result in a reduction of B. O. D. totally out of proportion to the oxidizing power of chlorine.

Pre-chlorination in sewer lines to prevent septic conditions and to maintain the sewage in condition for treatment goes forward each year. Its possibilities have been exhaustively reviewed by Bowlus and Banta.[48] The operations of the Los Angeles County Sanitary District in this connection should be once more recorded. The District covers an area of 200 square miles. Its sewage is transferred by trunk sewers on flat grades to a plant 15 miles from the center of population and industry and 20 miles from the most remote town. It arrives at the treatment works markedly septic, with its suspended matter highly comminuted and with large quantities of hydrogen sulphide. The activated-sludge plant, of normal design and of proper capacity, was inadequate to deal with the sewage in this condition.

After careful review of the condition of the sewage in all parts of the system, a pre-chlorination program was developed at strategic points including several packing-house outfalls. The results were excellent, the condition of the sewage was immediately improved and the capacity of the plant was increased almost threefold. The cost of treatment, exclusive of chlorination, was reported to be $23 per million gallons. Chlorine treatment added about $6.

Similar use of chlorine for the prevention of odors in trunk sewers is now practiced in the Elizabeth Valley, New Jersey, trunk sewer, where as much as 1000 pounds of chlorine are used per day during the summer season, and in certain of the Westchester County districts in New York State.

A novel use of chlorine has been developed by Goudey[49] in order to keep down bulking of activated sludge and to permit greater concentration of solids in the final settling tanks at Los Angeles. The top water in the clarifier is kept chlorinated and the sludge layer is affected very slightly, but sufficiently to prevent bulking. The chlorine dose varies from 2 to 3 p. p. m., resulting in residual chlorine in the final effluent.

An effort to regulate and prevent the aftergrowth of green algae in a tidal estuary, stimulated by the presence of a well nitrified sewage effluent, is reported from Baltimore by Keefer and Armeling.[50] The shallow tidal estuary, about nine miles long, developed growths of free floating algae in sufficient quantities to create objection in these waters, which are used for recreational purposes. The estuary receives the effluent from the Baltimore City sewage treatment plant. This plant treats 61 million gallons per day of sewage with trickling filters and post-sedimentation.

In this operation, chlorinated water treated with lime to form hypochlorite yielded in the sewage effluent residual chlorine tests with 60 per cent of the quantity of chlorine gas required for the same residual in the absence of lime. The time of the residual was extended from 6.7 to 11.3 hours, with a net saving in chemicals of 21 per cent, by the lime-chlorine arrangement. Between 3000 and 3700 pounds of chlorine were used daily, depending upon the water temperature. Conditions in Back River were markedly improved during this period, but there is some doubt as to whether this was due to the lime-chlorine application or to less favorable solar radiation, and more rainfall. A reduction of approximately 33 per cent of the 5-day B. O. D., however, was also observed.

The work of Halvorson, Fisher, and Fuller and Anderson, on packing-house wastes has been continued by Halvorson, Cade and Fuller with important findings. The chemical coagulation and precipitation of certain proteins in these wastes require a proportion of 2 to 1 of chlorine to nitrogen. The ratio is modified by the pH of the solution. Precipitation is likewise a function of protein concentration, so that in commercial operation the waste waters to be treated should be separated from other diluting waters.

The water to be treated should preferably contain more than 100 p. p. m. of organic nitrogen with a pH of about 4. Modified proteins, such as gelatin, require higher chlorine ratios; peptones, still higher ratios; and amino acids are not precipitated. Under the most favorable conditions, a recovery of between 40 and 85 per cent of the organic nitrogen was obtained with a chlorine-nitrogen ratio of about 1.5. The by-products re-

covered are used as hog food and as fertilizer, although their values for these purposes have not as yet been completely demonstrated.

Activated Sludge

Although the possible influence of industrial wastes on the activated-sludge process has retarded the rapid installation of new plants for activated-sludge treatment, the larger plants in this country now under construction are generally of this type. Objection to the process for smaller plants is also declining. The introduction of separate sludge digestion tanks for activated sludge and sludge drying equipment have strengthened the reasons for adoption of the process. The operation of the process with minimum odors and with initially low construction costs naturally give this type of plant considerable emphasis at this time.

The new plant at Peoria, Illinois, was designed to treat the sewage from a population of 140,000 with the addition of 8 million gallons of trade wastes. Studies of the application of the process to various types of trade wastes still continue. At the Michigan and the Iowa Engineering Experiment Stations, the applicability of activated sludge to the treatment of creamery wastes has been found to be not entirely satisfactory. At Kyoto, Japan, a five million gallon plant is being constructed to study the behavior of domestic sewage with dye-house wastes.

Considerable interest still centers around a discussion as to the exact mechanics of the activated-sludge process. Buswell[51] has recently given a historical review of the biology of activated sludge, referring to the bio-precipitation and the oxidation or nitrification groups of reaction. The bio-precipitation stage is reached quickly and the minimum quantity of air is required for its accomplishment. The experience of Hatfield and others operating pre-aeration plants confirm these observations. The findings lend some weight to the hypothesis that this stage is more physical-chemical than biological in nature. It leads also to the suggestion that a small amount of aeration of sewage entering the primary settling tanks, before the introduction of returned activated sludge, would offer some advantages.

Additional studies of the effect on purification by partial and complete disinfection of activated sludge have been carried out by Heukelekian.[52] Complications arose because of physical changes in the organic matter of the sludge itself, but chlorine and potassium cyanide appear to disperse the coagulated flocs.

Goudey's experiments at Los Angeles demonstrated that primary clarification in the activated-sludge process is helpful and that raw sewage solids are not essential in the aeration tanks to maintain good activated sludge.[53] Chemical precipitation with ferric chloride appears to Goudey to insure better results in the aeration tanks. He further predicts that,

with proper conditioning of the return sludge, a "super-activated-sludge process" will ultimately result, in which the sludge during re-aeration is adjusted to the proper ratio of bacterial and protozoal life in reference to food supply, in which chlorine will play an important part in liberation of enzymes, where the pH of the incoming raw sewage will have a controlling influence, in which bulking of sludge will be of no concern and in which the oxidation requirements will necessarily be more carefully observed.

Operation somewhat along the lines suggested by Goudey is reported from London, Ontario,[54] where sludge re-aeration continues for a long time, the aeration period of the mixed liquor is short and occasional chlorine is added to the activated sludge to restore its activity.

At Essen-Rellinghausen, Fries[55] arrives at the conclusion that the efficiency of the activated-sludge process is enhanced by the removal of the solids from the raw sewage.

Air Requirements

The pursuit of the effort to reduce the power requirements of the activated-sludge process continues unabated. Streander[56] has recently listed the average power requirements in various methods of introduction of air, as follows:

Type of Air Introduction	Horse Power Required per Million Gallons of Sewage
Spiral flow-diffused air	30 to 40
Shallow supended air diffusers	29
Simplex aerators	18 to 20
Submerged paddles with diffused air	15 to 18

In most of the present installations, however, the spiral flow tank is used. Until recently the filtros silica plate was most generally used for diffusion of the air, but recently the Norton Company with "Alundum" and the Carborundum Company with "Aloxite" have entered the competition. Tube diffusers of shallow submergence are being used at a number of plants, notably at Woonsocket, R. I., and Madison-Chatham, N. J.

At Phoenix, Ariz.,[57] good results are reported with a combination of diffused air and revolving paddle wheels using 0.25 cubic foot of air per gallon. The Dorr Company, interested in the development of this particular combination, claim that the same B. O. D. reduction is secured with 0.3 as with 0.8 to 1.5 cubic feet of air per gallon in the plate diffusion method. Muskegon Heights and Escanaba, Michigan, use a similar design.

Other methods of applying air are exemplified in the plants at New Canaan, Conn.,[58] and Barrington and Collingswood, N. J., with partly submerged paddle wheels or brushes, without air diffusion. Packing-house wastes are being treated at Beverwijk, Holland, and at Knocke-Zoute, Belgium, by a similar procedure.

Shorter aeration periods and longer sludge re-aeration are reflected in the plants of this type. The same tendency appears in the use of Simplex aerators quite extensively applied in England, but in the United States so far restricted to a few of the smaller plants.

Experimental observations on a combination of straight air diffusion with individual control pipes to each plate and revolving paddles with diffused air are being made at the Stahnsdorf, Berlin, plant in Germany.[59] Similar observations by Mieder and Viehl at Leipzig[60] on various types of aeration result in the judgment that, if complete treatment is desired, the submerged contact aerators will not do the job.

A number of plants in Germany[61] report minimum power requirements with the Kremer system of aeration, while Sierp[62] reports that in simple aeration alone 5 per cent of the applied oxygen is used up, while with the aid of paddles this figure is increased to 30 per cent.

Extensive experiments are also underway in connection with the program for the ultimate treatment of sewage at London, England. An experimental activated-sludge plant is now in operation for this purpose at Barking,[63] with a complicated system of routing the sewage in tanks equipped with paddles, and with upper and lower passes for the sewage. Diffused air is applied to the upper side of the lower pass.

Pre-Aeration

The speeding up of trickling filters by treating the sewage with aeration prior to application on the filters was first used at Birmingham, England, by Whitehead. He found that the rate of the trickling filter could be increased approximately threefold and somewhat later Hatfield, at Decatur, Illinois, used a similar adaptation on a strong sewage containing starch wastes. Later, Fort Worth, Texas, adopted the same principle in the treatment of a sewage containing packing-house wastes with the initial operation of a 16 m. g. d. plant in 1927.

Experiments have been in progress at Moscow, Russia, on the use of pre-aeration in combination with slag filtration, 9 feet deep. A similar plant exists at Bryan, Texas, where domestic sewage is being treated.

It is important to note that at Decatur, Illinois, where pre-aeration is practised ahead of trickling filters, aeration without sludge return apparently reduces equally as good results as aeration with return sludge or with return re-aerated sludge.

The findings at Fort Worth in general confirm those at Decatur, although considerable odor develops at the Fort Worth plant when under-aerated sludge is used. The removal of B. O. D. is quite high, however, and a satisfactory effluent is produced, in spite of the odors.

An interesting departure from the pre-aeration program has been developed by Hayes at Waco, Texas, where primary clarified sewage is passed

upward through stone beds or filters, with the introduction of a small quantity of air through a false bottom in the filter beds. Excellent results are obtained by using two sets of filters in series with a settling tank following each set. In the first set of filters, sulphur organisms predominate with a minimum of nitrifying bacteria. In the second set of filters, nitrate formers abound and the sulphur group is absent. The data may be interpreted to confirm the two-stage hypothesis regarding the activated-sludge treatment and to give further evidence of the fact that the sulphur oxidation cycle precedes that of nitrification.

Bulking of Sludge

The causes, origin and control of the bulking of sludge continue to be one of the most popular subjects for discussion. No definite answer to any of the elements apparently is on the horizon. The observations by Smit[64] indicate that the cause of bulking in normal sewages must lie elsewhere than in the presence of high amounts of carbohydrates such as glucose, sucrose, lactose and starch. Concentrations of these materials, normally present in sewage, do not affect adversely the character of the sludge. Half-hourly samples of Amsterdam sewage from three sewers showed a peak concentration of sugar of 80 p. p. m., whereas amounts well in excess of 100 p. p. m. do not materially influence the character of sludge, until concentrations approximating 300 p. p. m. were reached.

Experiments at the Chicago Sanitary District, Decatur, Illinois, and elsewhere confirm the fact that bulking is frequently accompanied by excessive growth of *sphaerotilus*. Haseltine[65] by careful microscopic examinations of activated sludge at Salinas, California, confirms the same fact. The findings, however, do not increase materially our knowledge of the functions of protozoa in activated sludge and particularly in arriving at estimates of the causes of bulking. In 1928, Kolkwitz referred to the fact that bulking indicated a lack of equilibrium between the absorptive and regenerative powers of the sludge. This lack of adjustment was merely indicated by increasing concentrations of *sphaerotilus*, which disappeared as soon as equilibrium was reëstablished.

Much more work on the subject evidently needs to be done, since the experiments at Chicago show that the growth of the organism was accelerated by soluble carbohydrates while Smit's observations indicate that fairly large amounts of carbohydrate were required to produce excessive bulking of sludge.

Even corrections of the difficulty are as variable as are the number of plants. Donaldson[66] controlled the difficulties at Tenafly, N. J., by the addition of lime to bring the pH up to 8.8, while Mieder and Viehl[60] went in the other direction at Leipzig, Germany, by reducing the pH to 6.5 by the addition of hydrochloric acid. Pre-chlorination in the latter instance

was unsuccessful, but additions of ferric chloride in relatively large amounts gave some relief as long as the chemical was added. One part per million of copper sulphate was also helpful.

More satisfactory efforts of controlling the bulking appear to reside in the assumption that the primary cause of sludge bulking is in the lack of sufficient air supply. Which of the many causes and types of control rest upon ultimately substantiated findings it is impossible to predict at this moment, in the light of current observations.

Townsend[67] is of the opinion that the bulking effect is largely, if not wholly, the result of retarded biochemical activity. He bases this conclusion upon his experimental observations that increasing the rate of aeration improves the settling characteristics of the sludge. He does not, however, overlook the possibility that flocculation is likewise important and that the physical rather than the biochemical characteristics may determine the result.

Further evidence on the relative importance of purely physical changes appears in the observations by Clifford and Windridge,[68] who studied the influence upon the rate of sedimentation by the specific volume of the sludge, with the specific gravity kept constant. Below a certain critical concentration, about 25 per cent by volume, sedimentation is virtually independent of concentration. Above this point, however, a small increment delays sedimentation disproportionately. The critical concentration is less, however, with a poorly aerated sludge. The physical characteristics of the sludge are particularly emphasized by the authors as controlling factors.

In the discussion of the paper by Clifford and Windridge, the obvious complications introduced by such industrial wastes as iron salts and wastes from tanneries, wool scouring and wine manufacturing were emphasized.

Settling Tanks

No real progress in variation and design of settling tanks appears at the moment, unless the sludge settling tanks with central inlets and peripheral weirs meet some of the expectations of their sponsors. Hypotheses of settling have been presented in recent months, particularly by Schlenz before the Texas Water Works School in January, 1933. He concludes that a multiple settling tank or tray clarifier would fulfill most of the theoretical requirements of activated-sludge settling. The field is obviously one of considerable importance if it is borne in mind that "the oxygen requirements for sludge drawn from the bottom of clarifier tanks may easily exceed 10 mg. of oxygen per liter of sludge per minute. Anaerobic conditions probably prevail at the bottom of all clarification tanks as now designed."[69]

Digestion of Excess Activated Sludge

Recent developments at the San Antonio plant and at Chicago in the digestion of activated sludge show that the same solids concentration cannot be reached in the digester as when digesting raw solids. The average solids content of raw sewage sludge was 4.5, of excess activated sludge, 0.8, of the mixed solids entering the digester, 1.3, and of the digested sludge, 2.75 per cent. The findings confirm the general opinion that more sludge digestion capacity must be provided for digesters at activated-sludge plants than at other types of plants.

The general practice in this process is to return the excess activated sludge to the primary settling tanks, in the effort to concentrate the solids.

The character of supernatant overflow liquors from activated-sludge digesters is giving considerable concern to the operators. At San Antonio this liquor was first returned to the sludge re-aeration tanks with considerable resultant difficulty, interfering with the efficiency of coagulation. Similar efforts at Waco, Texas, produced the same results. At Fort Worth the supernatant liquor was returned to the incoming raw sewage with less disturbance, but odors at the plant were materially increased. In recent months San Antonio has begun the return of this liquor to the incoming raw sewage with reduced detrimental effects.

Mechanical and Chemical Processes

Three installations, one of full size, and the other two on an experimental scale, using chemical precipitation for sewage treatment, have attracted considerable attention during the year.

The sewage treatment plant at Dearborn, Michigan, was put in operation late in 1931.[70] The process used is chemical and mechanical, and consists of coarse screening, precipitation with ferric chloride, lime, paper pulp and grit, followed by rapid upward filtration and chlorination. The filtering material is crushed magnetite which is cleaned by a traveling magnet, which lifts it from its supporting screen. Sludge is dewatered by vacuum filtration. Changes which are proposed or already under way make the published results of little value in estimating the efficiency and economy of the process. The plant has been described in *Engineering News Record* for February 18, 1932, and in *Water Works and Sewerage* for October, 1931, October, 1932, and January, 1933.

An extensive laboratory series of experimental tests relating to chemical coagulation in sewage, and another series of tests of the adsorption of amino nitrogen from clarified sewage have been carried out in the experimental laboratories of Guggenheim Brothers in New York City under the general direction of G. H. Gleason. These led to the development of a complete process of sewage treatment described briefly by E. A. Cappelen Smith[71]

and in more detail by Gleason and his associate, Alfred C. Loonam[72] before the New York State Sewage Works Association, January 17, 1933. After considerable preliminary investigation of the general subject of coagulation of sewage, the chemicals selected were ferric sulphate and lime in proportions to give pH values varying from 6 to 8.

Similar investigations with various means of absorbing amino nitrogen resulted in the selection of a zeolite, which is used as a filter medium.

The process selected for a continuous experimental test included coagulation with ferric sulphate and lime, sedimentation, filtration, drying and incineration of sludge, with recovery of the iron by treatment of the ash with sulphuric acid, removal of basic nitrogen by treatment with zeolite, and regeneration of the zeolite, concentration of the basic nitrogen and subsequent recovery of ammonia.

Upon the basis of the published results, expressed in parts per million, suspended solids are reduced from 200 to 0; B. O. D. from 150 to 5; total nitrogen from about 25 to 2; ammoniacal nitrogen from 13 to less than 1. A bacterial removal of 99.8 per cent is obtained. Preliminary cost estimates indicate operating costs of about $22.00 and total fixed charges of an additional $14.00 per million gallons treated, no credit being taken for by-product recovery. Although based on the operation of a laboratory installation, constructed entirely of glass, and treating only 2500 gallons of sewage per day, the claim is made that these cost estimates will hold good for a plant treating 50 million gallons per day, and that such a plant can be built for approximately two-thirds of the cost of an activated-sludge plant of the same capacity. The prediction is probably a dangerous one, without plant-scale confirmation. A larger plant, with a capacity of 25,000 gallons per day, is now (June, 1933) in operation at the North Side Treatment Works of the Sanitary District of Chicago.

The process has received wide publicity as a new method of sewage treatment, but it appears to embody no novel features, with the exception of the zeolite treatment, recovery of ammonia and regeneration of ferric sulphate.

Instead of providing a source of revenue, zeolite treatment and recovery of ammonia may add to the cost of operation. Both in England and America many gas works have abandoned their ammonia recovery plants, and are discharging the crude ammoniacal liquor directly into the sewers, because of the extremely low price obtainable at present for ammonia in competition with the German and Belgian product.

It is unfortunate that, in many of these experimental processes, the claim of originality is made for the entire method, although the novel feature may constitute only one step in the process, as the zeolite treatment, or it may be an alternate method of manufacturing a chemical reagent, which has no bearing on the precipitation process.

Treatment with ferrous and ferric salts and lime was in use in England sixty years ago, and the same method received favorable mention in Allen Hazen's report of his work on chemical precipitation at Lawrence in 1889. In this connection it is interesting to note that he suggests the oxidation of ferrous sulphate by treatment with chlorine, a method which has reappeared in recent years in the manufacture of chlorinated copperas for sludge conditioning and water treatment.

These three modern installations have served to reaffirm one of Mr. Hazen's conclusions, that with the use of a proper amount of either an iron or aluminum salt from one-half to two-thirds of the organic matter may be removed by chemical precipitation. Unfortunately disproof of his other conclusion has not yet been presented that the incompleteness of the purification in comparison with the cost of the process may confine the application of chemical precipitation to within narrow limits.

The use of ferric chloride as a coagulant has been investigated at a small experimental plant at Palo Alto, California, and a preliminary report of this work was presented before the Texas Section, South West Water Works Association by Harvey O. Banks.[73] A detail of particular interest is the attempt at regenerating the spent coagulant by chlorination and returning it to the influent of the sedimentation system. Promising economies were indicated during the initial stages of these studies, but it was finally found that as the regeneration of the coagulant was continued the specific gravity of the floc decreased continuously to a point where it would no longer settle out, while the chlorine consumption increased with each successive regeneration. The plan finally adopted, as representing the maximum utilization of the coagulant, was clarification by plain sedimentation, mixing with ferric chloride in a circular mixing tank provided with paddles turning at 10 r. p. m., passing to a second mixing or coagulating tank with similar paddles operating at 3 r. p. m., secondary sedimentation, and returning the precipitated floc from this latter stage to the primary influent. A removal of 85 to 90 per cent of the suspended solids and 80 to 85 per cent of the B. O. D., together with satisfactory disinfection, is indicated at a cost for chemicals alone of $9.90 per million gallons.

Stream Pollution

The year 1932 has been characterized by the growth of organized movements in the direction of stream control rather than by any outstanding developments in chemical or biochemical theories. The laboratory investigations of the U. S. Public Health Service group at Cincinnati, which have in the past provided so much of our basic scientific data, have been continued as heretofore, but have by no means reached a point of final summation and interpretation. Various interdependent relationships have been shown to exist between the chemical constituents of polluting materials, the bac-

teria and the higher microscopic organisms, the plankton. This has necessitated diverse lines of investigation, and has made final analysis difficult. Excellent summaries of the present status of this work and some probable interpretations have been made by Hoskins[74] and by Streeter.[75]

It is now believed that the oxidation process goes along with bacterial multiplication and is not necessarily related to numbers of bacteria present. If growth is retarded or stimulated, the rate of oxidation is correspondingly modified.

In any given situation bacteria tend to reach a self-limited concentration after which oxidation ceases. Reduction in bacterial density by the protozoa, or other agency, leads to increased bacterial multiplication and increased rate of oxidation. Dilution also disturbs this biological equilibrium and the entrance of a pure stream into a polluted stream may lead to further multiplication of bacteria and even to actual increased density. It is suggested that this is due to the simultaneous dilution of the protozoa and their slower rate of reproduction, thus providing temporarily a higher permissible bacterial density. The evidence from streams investigations indicates an increase in the daily per capita contribution of *B. coli* organisms of from 5 or 10 billion in the feces to 250 billion in the streams. An initial increase is generally measurable within a few hours from the sewer mouth, the maximum density being reached more quickly in summer than in winter.

The ultimate mechanism of self-purification in streams, as measured by the disappearance of bacteria of sewage origin, can at present be recognized only as a complex of many factors in which food supply and biological competitions play a predominant rôle. Self-purification, as measured by the disappearance of organic pollution, lends itself better to laboratory measurement and its basic theoretical concepts are accordingly better understood. The rate of oxidation during the initial stage proceeds by a well established law in which the constants have been satisfactorily determined and may be regarded as well established. This law is expressed by

$$\log \frac{L}{L - X_t} = K_T \qquad (1)$$

$$K_T = 0.1 \times 1.047^{T-20} \qquad (2)$$

in which L is the initial oxygen demand of the pollutional material, and X_t the amount of demand satisfied in t days, the temperature of the water being T degrees C.

When this first stage, which represents the oxidation of carbon, is about 90 per cent completed the influence of a second stage, the oxidation of nitrogen, begins to predominate. The form and constants of the equations of this reaction are not at this time so precisely known. The investiga-

tions of Theriault, however, have indicated the importance of giving proper attention to its influence, especially in the study of well oxidized effluents.

The oxygen demand corresponding to the first stage approximates a quarter of a pound per capita per day, which controls the result up to about the 10th day, and in most cases this suffices for a complete statement.

Pure research of this type merges imperceptibly into that phase of research usually described as stream investigations. The U. S. Public Health Service has continued its stream pollution investigations and has completed a resurvey of the entire Ohio River Basin for comparison with its studies of 1913–16, and has likewise completed a similar investigation of the upper Mississippi River and a resurvey of the upper Potomac.

Several other investigations of stream conditions in the United States are likewise worthy of comment. The conditions of the waters of the upper Potomac River, which are variously used by certain Maryland communities and industrial concerns and in which the public, as represented by the Isaac Walton League, likewise has an active interest, had become a matter of serious concern. The State Board of Health of Maryland, through its Chief Engineer, Mr. Abel Wolman, called a conference of these various interests through which there was later organized a joint board, known as the upper Potomac River Board, to make studies of stream flow and stream pollution. The expenses of the investigation were jointly financed and much of the analytical work was done in the laboratories of three industrial concerns and of the city of Cumberland. Details of plant operations have been investigated and individual problems of industrial wastes and their disposal have been discussed. Voluntary improvements have been made from time to time as these have been suggested by the results of the studies and a most noticeable improvement in the general condition of the stream has been effected. The unpublished report of the Board, dated September 11, 1931, concludes with these words:

"The industrial plants working together in this task have been at considerable expense to carry on this study of water quality and stream flow. They have spent hundreds of thousands of dollars to rectify the fluctuating conditions of the river water to make it usable in their plants."

Many of the state departments have been active in stream pollution investigations, particularly with reference to industrial waste pollution. An excellent summary of much of this work was developed in a symposium on stream pollution and industrial wastes at the 24th Annual Meeting of the American Institute of Chemical Engineers held in December, 1932.[76]

Mr. W. L. Stevenson, Chief Engineer of the Pennsylvania Department of Health, outlined the policy which has been so successfully maintained in Pennsylvania, of state investigations of stream pollution with groups of industries of the chemical type. For example, the tanning industry in

Pennsylvania has invested $61,000 during the past six years in coöperative investigations into a solution of their specific disposal problems. The state's contribution to this same project has been $29,000. Doctor W. Rudolfs of the New Jersey State Agricultural Experimental Station discussed the industrial situation in New Jersey which probably represents industrial pollution in its most concentrated form. Something over 200 million gallons per day of industrial waste are discharged into New Jersey's streams in addition to the sewage of cities and approximately 750,000 pounds of oxygen are required daily to meet the combined demand of these wastes. The usual measuring stick of oxygen demand, however, does not sufficiently describe the damages resulting from various industrial wastes which in any case result from specific properties such as acidity, toxicity, etc.

In another place Rudolfs[77] discusses in greater detail a specific instance which has been the subject of investigation by him for several years, namely, the industrial pollution of the Raritan River. This river is used as a source of public and industrial water supply and quite extensively for recreational purposes and it also constitutes the drainage system for a highly industrial population of some 210,000. It was determined that remedial treatment to the extent of 50 to 70 per cent of the total present burden must be applied to permit the river to again become self-sustaining and that, for recreational purposes, additional relief through chlorination is demanded during the summer months.

Mr. W. E. Wise, Engineer of the State Water Commission of Connecticut which commission functions in coöperation with the State Health Department in administrative control of stream pollution, outlined a program of studies dealing with all the important waste waters of the state. This commission is under the necessity of prescribing a satisfactory method of treatment before it may issue orders under the general anti-pollution laws. Studies under way include experimental treatments of the wastes from the metal industries, particularly brass-working plants, bleacheries, tanneries, laundries and others.

The problems of the starch and beet sugar industries were outlined by Professor Edward Bartow, University of Iowa, and those of the pulp and paper trades by Mr. C. M. Baker, Engineer, American Pulp and Paper Association. Mr. Baker showed an incidental fiber recovery valued at $100,000 annually as a return upon a capital expenditure of $41,000. In general, however, the speakers were of the opinion that waste disposal must be frankly faced as an added cost to industry.

Further reference to the activities of the State of Pennsylvania are found in a paper by C. F. Drake[78] upon the effect of acid mine drainage upon river waters in Pennsylvania. Statistics of the soft coal production and a summary of reports and papers on the subject of mine drainage in Pennsyl-

vania are given. Since 1923 the State Sanitary Water Board has carried out extensive investigations of possible remedial treatments but as yet is unprepared to recommend any satisfactory solution to this long-standing problem. Judicial decisions in the state have varied and the decision of the Supreme Court of the State in the Sanderson case[79] to the effect that the discharge of acid mine drainage into a stream constitutes a reasonable and lawful use has been repudiated in certain other states.

Mr. R. D. Leitch[80] has also investigated a series of 39 mines, mostly active, in the pyritic coal region. He finds the reaction of the drainage water in the various mines to be from alkaline to 14,000 parts per million total acidity.

The stream pollution regulations of the state of New Hampshire, and the polluted conditions of certain of the state's rivers and lakes, with a plea for preservation of these natural resources for their recreational value, have been reviewed by Howard.[81] A progress report of the Committee on Water Pollution of the State of Wisconsin summarizes the activities of this committee since 1925. Industrial wastes and their experimental treatment consume a large part of the studies. The broad-minded attitude of the paper industry in particular is pointed out.

A Report of the Rhode Island Board of Purification of Waters, charged with authority to regulate and prohibit stream pollution, reviews progress in sewage treatment. Ninety-two per cent of the municipal sewage of the state is treated before discharge. Continued activities against industrial pollution, especially those from oil refineries and oil handling, are reported.

In Great Britain there is evidence of increasing activity both in actual stream pollution investigations and in public discussion of these questions. The Board of Water Pollution Research have carried on investigations on the River Tees especially with reference to the destruction of salmon and sea trout in the waters of the estuary. Lethal doses of cyanide and presence of coal tar acids were found. Experimental studies upon the rate of breakdown of these and other impurities are under way.[82]

These activities are typical of those of the various British River Boards, notably the West Riding of Yorkshire,[83] and also of those on the Continent, the Ruhrverband on the River Ruhr,[84] the Magdeburg River Research Board on the upper waters of the Elbe[85] and the River Research Board at Breslau on the upper waters of the Oder.[86]

In each case, and in numerous other instances, joint boards have taken over functions of investigation and consultation with powers to make arrangements, and in some cases with authority to construct works. The activities of the Ruhrverband and of the correlative body, the Ruhr Reservoir Association, are of especial interest as exemplifying consolidation of all these lines of activity. A project involving the construction of eight lakes of a total area of $4^1/_2$ square miles and capacity of 6.5 billion gallons is

under way. Lake Hengstey, providing normally for 34 hour detention of the Ruhr waters, has been completed and has shown excellent efficiency as a purifying mechanism. The completion of the entire system is expected to restore the river to a high degree of purity.

A noteworthy piece of institutional research was reported by H. G. Baity of the University of North Carolina,[87] being the results of a four-year study of the pollution of a small stream by the sewerage works of Chapel Hill, North Carolina. Professor Baity was particularly interested in the question of the reduction of oxygen demand by means of chlorination. This possibility was first referred to by Cohen of Texas and as the results claimed were quite excessive, when regarded in the light of the oxygen equivalent of the available chlorine used, they were viewed with some scepticism. Later work by Tiedemann and others of the New York State Department of Health carried out at Huntington, Long Island, definitely confirmed the Texas results and made it necessary to postulate a chemical change in the organic material which could not be regarded as mere oxidation, but which did remove from the realm of further bacterial change a considerable amount of the pollutional material. Accurate data upon this very suggestive possibility have been needed for some time and are supplied by Baity's studies.

Chlorination of the sewage indicated apparent oxygen demand reductions of from 25 to 40 per cent by the usual analytical procedure, but in view of the difficulties outlined above and of possible alternative explanations of the reduction, the author was unwilling to accept the results as final. During the year 1930 stream flow conditions were low and uniform and provided an ideal situation for a test of the stream itself. By alternating periods of chlorination and nonchlorination and surveying the stream at various stations below, he obtained positive evidence of a real reduction in oxygen demand sufficient, in his opinion, to warrant the conclusion that the values obtained at the plant represented the true conditions from the point of view of stream pollution.

In this same connection, however, we note that Calvert of Indianapolis[88] was unable to observe any change in the stream condition below the outfall of the activated-sludge plant, the effluent of which was experimentally chlorinated. The B. O. D. of the effluent itself was reduced by less than 10 per cent. These results are quite in harmony with the general view that chlorination acts upon the more readily oxidizable matter to bring about a material reduction in its availability as a bacterial food.

The progressive increase in the salinity of a stream following its repeated use in irrigation is shown by C. S. Scofield.[89] The total salt content of the Rio Grande River increases from 610 at Leasburg to 2206 p. p. m. at Fort Quitman.

The mystery of bacteriophage continues to occupy a certain place in

the literature, especially that from abroad. Professors Gildmeister and Wantanabe[4] in the course of a study of phage from the waters of the Spree, above and in Berlin, and also from the waters of a nearby lake have concluded that the river water normally contains insufficient phage to be of any consequential influence in self-purification. Upon preliminary incubation, however, with broth, 24 hours at 37°, phage was developed in sufficient intensity to react with such organisms as typhoid, paratyphoid, coli and "Ruhr group." The largest quantities of phage were found in the stream during freshet and the smallest quantities during dry weather. The authors conclude that phage results primarily from the wash of polluted ground surfaces and that it does not normally occur in streams as a result of the presence of pollutional organisms to a sufficient degree to have any germicidal properties.

Several investigations have dealt with the subject of fish life, either directly or inferentially. In addition to the work on the River Tees, previously mentioned, the work of Abeling[90] upon the wastes from beet sugar factories is particularly suggestive. In the reaction of sanitary chemists against the all too prevalent view of the laity that industrial wastes in general are poisonous to fish, when in most cases we know the detrimental effect to be primarily deoxygenization, there has been too great a tendency of late to overlook the possibilities of the discharge of poisonous substances. The Tee study shows conclusively that oxygen depletion was not a sufficient explanation of fish mortality which was found to be due in fact to lethal doses of cyanide. Abeling's studies similarly have shown a toxicity in beet sugar wastes due to the so-called beet-saponin. The acid form of this substance is sufficiently soluble in the wastes to be definitely toxic. The toxic limits for fish, species unnoted, is given as 5 milligrams per liter.

Wiede[91] has presented data upon the lethal limits of arsenic in the form of oxide with the view primarily to controlling the use of arsenicals which are being used to some extent to prevent the growth of vegetation in fish ponds. Arsenic oxide up to 7 p. p. m. exerted no ill effects upon fish.

In a study of the biology of waste waters resulting from the process of flax retting, in addition to the high B. O. D. of the waste in these waters, Lehmann[92] finds them specifically harmful to fish.

Baird and Duff[93] obtain similar results on the toxicity of these waters. They attribute the toxic properties specifically to butyric, succinic and probably acetic acids whose effects were neutralized by careful adjustment with lime water.

In the field of general administrative policy, apart from programs of investigation, the Tri-state compact, negotiated by commissioners representing the states of New York, New Jersey and Connecticut and ratified by the New York State Legislature in 1932, represents an important stage in a long line of investigations, reports and administrative activities that have

been associated with the pollution of New York Harbor, Long Island Sound and tributary waters.[94] The compact which shall become effective as to the states of New York and New Jersey upon ratification by them and as between the three states, when ratified by the state of Connecticut, provides for an "Interstate Sanitary District" and an "Interstate Sanitary Commission." The district extends from the easterly side of New Haven Harbor, the easterly side of Port Jefferson Harbor and the easterly side of Fire Island Inlet, on the east, to the southerly side of Manasquan Inlet on the New Jersey coast. It extends up the Housatonic River to the towns of Stratford and Milford, up the Hudson River to the New York-New Jersey boundary and throughout the tidal waters of the New Jersey tributaries.

The commission is empowered to classify these waters into Class A, waters expected to be used primarily for recreation purposes, shell-fish culture or the development of fish life, and Class B, waters not expected to be used primarily for such purposes. Sewage to be discharged into Class A waters shall be treated to remove all floating solids and at least 60 per cent of the suspended solids, to reduce organisms of the *B. coli* group to a probable density of one or less per cc. in at least one-half the samples of effluent tested by the presumptive method and to reduce oxygen demand so that the D. O. of the waters in the vicinity may be maintained at not less than 50 per cent of saturation, at 5-foot depths. Where bathing is a primary consideration the bacterial standard need be applied only during the bathing season. Sewage to be discharged into Class B waters shall be treated to remove all floating solids and at least 10 per cent of the suspended solids or such additional amount as may be necessary to avoid sludge deposits, and to reduce B. O. D. sufficiently to maintain not less than 30 per cent of D. O. saturation at a depth of 5 feet below the surface and during any week of the year.

The commission is empowered to conduct hearings and to issue orders prescribing reasonable dates of compliance with these standard specifications by the municipalities. It may also investigate and determine if the requirements have been complied with. It may likewise bring action in its own name in the proper court to compel enforcement of these provisions and of its orders, although primary enforcement and general regulation remain in the hands of the respective state departments.

Certain international complications appear from time to time and during 1932 attention has once more been directed to the pollution of the Great Lakes and connecting rivers between United States and Canada in a paper by Ferguson.[95] A treaty of 1909 between the United States and Great Britain provides, among other things with respect to the international waters, that they "shall not be polluted on either side to the injury of health or property on the other." These matters were the subject of an exhaustive investigation by the International Joint Commission during the

years 1913 to 1916, as a result of which it was found that the St. Clair, Detroit and Niagara Rivers and certain portions of the Great Lakes were polluted in contravention of this treaty and that remedial works were called for.[96] Specific recommendations were made, based upon the most lenient interpretation of the words of the treaty, and the two worst offenders, the cities of Detroit and Buffalo, have taken steps looking toward amelioration of these present conditions and conformity to the treaty obligations. Ferguson points out, however, that little practical improvement has as yet been brought about.

Soenen[97] discusses another international situation in the pollution of the Upper Escaut in Belgium by the waters of the Espeirres, a French stream heavily polluted by textile wastes at Raubaix and Tourcoing.

Saville[77] has recently reviewed the entire world-wide field of waterways pollution in its administrative and governmental aspects. He tells of the growth and present state of development of the European plan of rivers boards having various types of organization and degrees of authority. He points out that even the British system is not perfect, that it has worked satisfactorily in only a very few cases and that there has been much complaint against its apparent unworkableness.

Applying all this experience, as well as our own in various types of administrative organization, Saville discusses the constitutional limitations to Federal control of water ways and the advantages of control by drainage area units, and developes his own line of solution about as follows: He would entirely exclude the Federal Government from administrative functions, but preserve its present research organization with enlarged scope and possibly with judicial powers available as a means of arbitration between states as an alternative to suits before the Supreme Court. He would develop and adequately support rivers boards within the state responsible only to the state authority, but having powers to join in interstate boards for the control of entire drainage areas either by treaty or preferably by less binding procedures.

The weakness of Saville's position seems to lie in the geographical fact that most of our great streams are many times interstate and that it has yet to be satisfactorily demonstrated that our sovereign states will limit their authority either by treaty or by gentlemen's agreements to the extent necessary for satisfactory joint administration of entire drainage areas. When, as Saville points out, the United States is at the present moment violating a treaty with Great Britain concerning the pollution of our northern boundary waters, a fact officially recognized by the International Joint Commission in 1916, it seems even more certain that individual state interests will always be held superior to those of composite drainage districts. This feature of our problem alone distinguishes it sharply from the similar situation in Europe.

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History of Chemical Precipitation*

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Process.—The process of sewage treatment known as chemical precipitation consists in the addition to raw sewage of such a chemical or of such chemicals as will, by reaction with each other and with the constituents of the sewage, produce a flocculent precipitate. The purpose is to coagulate as much as possible of the suspended, colloidal and dissolved constituents and thus make their sedimentation more rapid and complete. The precipitate may form around particles of sewage matter and as it settles may entangle others.

English Experience.—In 1762 a patent was granted to de Boissieu for purifying dirty water by a chemical process. During the hundred years thereafter many patented processes were devised and the chemical process became well-established in England. In 1857 the Chief Inspector of the General Board of Health recommended preparing compost from sewage solids obtained by precipitation, mentioning lime, alum, iron sulphate, etc., and believed the method to be suitable and safe from the health standpoint. The report of the Royal Sewage Commission in 1865 recommended land treatment and stated that chemicals could not render sewage non-putrescible although they could make it clear. The second Royal Commission on Rivers Pollution in 1870 ranked filtration as best, irrigation next and chemical processes as somewhat less efficient in removing *suspended* organic matter, but pointed out the great superiority of land treatment in removing about twice as much *dissolved* organic matter.

Plain sedimentation had been used for many years along the most contaminated streams to reduce nuisances; in many places the results were unsatisfactory due to plant mismanagement, a condition which naturally paved the way for the increased use of chemical processes. The views of the government experts, maintained practically unchanged for forty years, were not shared by many local authorities and hundreds of chemical processes were promoted by individuals and patented. Lime was used in most cases but often in combination with other substances. Splendid results were obtained in laboratory experiments and even in experimental plants which led to persevering attempts to develop the process. It is said that Salford tried thirteen different methods, Birmingham seven, and almost every large city several. Some processes, notably the A.B.C. process about 1870 using alum, blood, charcoal and clay, were boomed because of supposed value of their sludges for fertilizer.

The failure of plain sedimentation to effect thorough clarification and

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the hope of financial gain through recovery of manurial value caused the chemical processes to be hailed as a solution for existing troubles. This process was at its height during the decade from 1880 to 1890 when almost all new installations were of this type, until there were approximately 200 plants in England. Installations continued into the nineties when bacteriological methods began to receive attention. The hope of financial gain from the sale of fertilizer was not realized mainly because the cost of preparing it from the wet sludge was too great; furthermore the effluent, while clear, was found to be putrescible. The second Royal Commission in its 1908 report limited the use of chemical processes to strong sewages and those containing certain trade wastes. Beginning about 1910 the process passed from favor and most of the plants were converted into plain settling or septic tanks followed by biological processes.

French and German Experience.—Government experts in France held similar opinions to those in England. In 1874 the Seine Pollution Commission reported in favor of irrigation expressing the opinion that treatment with chemicals, in particular alum, would not constitute a complete and practical solution of the problem.

Early local requirements in Germany were based largely upon contemporary English opinions and about 1890 chemical precipitation was adopted at several places with confirmation of the results in England. When it was found that this method was unsatisfactory, sewage treatment took a different turn from that in England through the development of mechanical screening and sedimentation.

United States Experience.—The first chemical precipitation plant in the United States was completed in 1886 and several plants were installed during the next ten years but the process never met with as much favor here as in England.

Chemicals.—A list of the chemicals recommended and adopted from time to time would be long; the ones most extensively used, however, have been lime, copperas and alum. These three chemicals were most popular due to their simplicity and effectiveness under ordinary conditions.

Lime has been the most widely used of all due to low cost and rapid action; it was applied in the form of milk of lime after grinding, slaking and diluting, and thorough mixing with the sewage was required. From one-half to three-quarters of a ton of lime was required per million gallons treated; Hazen in 1890 pointed out that a certain definite amount was desirable, too little allowing incomplete precipitation and too much allowing secondary offensive decomposition.

Copperas and lime have been used less often and although copperas was more expensive than lime the amount of lime was so reduced that a saving in total cost was often effected; the precipitate was also more voluminous than that with lime alone.

Alum, while more costly than lime or copperas, proved to be advantageous for small plants.

English Plants.—The sewage of London, originally discharged into the Thames raw until nuisances became unbearable, and later stored for discharge on the outgoing tide, caused numerous complaints of the condition of the river, so that chemical subsidence was decided upon, employing copperas and lime. The Barking Plant of thirteen tanks was built in 1889 and the Crossness Plant of six tanks in 1892. A removal of 75 to 80 per cent of suspended solids was effected and the sludge, amounting to 40 cubic yards per million gallons or 0.8 per cent of the volume of sewage, was transported by tank steamers 40 to 50 miles out to sea and dumped. The chemical process was abandoned during the war because of cost and difficulty of obtaining chemicals and plain subsidence was adopted.

At Glasgow, after considerable hesitation between the biological and chemical method, the latter was finally adopted, employing alum and lime. At the Dalmarnock Plant the sewage contained considerable free acid and iron wastes from wire mills, which reacted favorably with lime. The sludge produced amounted to 50 cubic yards per million gallons, or nearly 1 per cent of the volume of the sewage. A portion of the sludge was pressed and sold but most of it was transported forty miles to sea and dumped. The process is still used at three plants in Glasgow.

At Salford alumino-ferric, a crude alum, was still being used in 1926 prior to trickling filters; at Leeds, with peculiar trade refuse, septic tanks were abandoned and chemical precipitation was adopted to reduce the load on trickling filters.

German Plants.—At Leipzig an iron salt was employed resulting in sludge with a volume of 24 cubic yards per million gallons or 0.4 per cent of the amount of sewage; nevertheless, on account of the character of the sewage, effecting a higher clarification than at London and Glasgow. Frankfort-on-the-Main and Wiesbaden were other cities which installed chemical precipitation about 1890.

American Plants.—Early chemical precipitation plants in the United States completed 1886–1893 were East Orange, Long Branch, Mystic Valley, White Plains, Sheepshead Bay, Canton, Chautauqua and the Chicago Fair.

The plant at Worcester, Massachusetts, was completed in 1890 and enlarged in 1893 and was probably our best known plant. Worcester was originally granted by the Legislature the right to use the brooks as sewers, but by 1880 complaints began to come from the towns below and the Legislature forced sewage treatment. It was the first large American city to treat sewage before discharge into a watercourse. As the sewage contained large amounts of trade wastes containing iron, lime only was used, amounting to approximately one-half ton per million gallons. The

flocculated sewage was settled in six roughing and ten final tanks. The removal of suspended solids was 85 to 90 per cent and of organic matter about 50 per cent. Records covering the period 1899 to 1916 showed the sludge as removed from the tanks to vary from 90 to 97 per cent water content, which after pressing was reduced to 68 to 74 per cent. Filter presses were installed in 1898. The sludge cakes were used for fill in a deep isolated valley for fertilizer or were dumped at sea. In 1898 the city began the construction of intermittent sand filters which were enlarged from time to time; in 1916 about three-quarters of the sewage was treated by chemical precipitation and one-quarter by plain sedimentation, the effluents being applied to the filters. In 1925 the old plant was abandoned and Imhoff tanks and trickling filters are now employed.

The largest chemical precipitation plant ever built in this country was completed at Providence in 1901, designed after a careful study of the results abroad and at Worcester. Chemical precipitation was recommended as providing sufficient treatment at a lesser cost than the more effective process of irrigation. There were four roughing tanks and sixteen finishing tanks. During 1911–12 and 1919–20 the plant was operated as a plain sedimentation process, otherwise lime was used. The sludge was passed through filter presses and was used for filling low land up to 1908 after which time it was conveyed by scows to a dumping station in 75 feet of water. For some years the Providence plant was the only large plant still operating, but it was abandoned in 1931, the old tanks being remodeled for an activated sludge plant.

Results.—Under favorable conditions the results of chemical precipitation were found to be about as follows: removal of suspended organic solids 80 to 90 per cent, removal of dissolved organic solids 20 to 30 per cent, removal of total organic matter 50 to 60 per cent, removal of bacteria 80 to 90 per cent. Chemicals used were 0.25 to 0.75 ton per million gallons, the volume of sludge produced was 25 to 50 cubic yards per million gallons, and the cost of pressing sludge into transportable cakes was almost as much as or more than the cost of precipitation.

The remaining suspended and dissolved organic matter caused the effluent to be putrescible and, while the quality was sufficiently good in some cases, in others it was most disappointing. The improvement over plain subsidence did not seem to be commensurate with the cost. The amount of sludge was over 50 per cent more than from plain subsidence. The hope of financial gain from manurial value of sludge did not materialize, most of the plants receiving no income whatever, and while sludge presses partly solved the sludge bugbear the handling and disposal of the large volume of sludge produced was inconvenient and expensive. Improvements in the process of plain sedimentation, development of biological filter processes and development of disinfection led to the abandon-

ment of practically all chemical precipitation plants. However, a limited field remained for sewages high in certain industrial wastes or where temperatures were unfavorable for biological processes, and for temporary use when plain sedimentation was insufficient. All of the old plants using this process in this country have now been abandoned; and only a few, such as Leeds and Glasgow are still operating in Europe, where the sewage is highly charged with trade wastes or where the cost seems justified by the increased rates of filter operation.

Brief mention should probably be made of some special processes employing chemicals which have developed during more recent years. The recovery of grease from sewage containing large amounts of wool-scouring wastes has been proved feasible by the addition of sulphuric acid. This process is in use at Bradford, England. A modification proposed in this country as the "Miles Acid Process" used sulphurous acid instead of sulphuric. Another process known as "direct oxidation" employing lime precipitation and simultaneous electrolysis has been developed during the last twenty years and used experimentally at Elmhurst, N. Y., Phillipsburg, N. J., Allentown, Pa., and in a permanent installation at Winston Salem, N. C. Conflicting opinions with regard to its merits have been expressed by experts. During the last year a revival of interest in chemical precipitation has been caused by the experimental plant at Palo Alto, treating settled sewage with ferric chloride, and additional interest would be stimulated if it should be found practicable and economical to treat raw sewage similarly.

Observations on Changes in Numbers of Bacteria in Polluted Water

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In sewage-polluted streams, after the maximum bacterial concentration has been reached, bacteria of the varieties included in the usual standard quantitative determinations tend to a quite consistent and rapid decrease in numbers.* When waters from such streams are collected in artificial containers, regardless of the point of collection, and held in the laboratory, the usual initial tendency is to a very considerable increase in numbers of bacteria, regardless of the condition of the sample, rather than to the decrease which is usually observed in the stream.

This apparent divergence between the bacterial changes which take place in natural streams and those which take place in the same waters under usual laboratory conditions has to a large extent blocked progress in experimental studies which might serve to extend and clarify our knowledge of the factors which control bacterial purification in natural streams. Certainly no extensive progress is to be expected until we are able to reproduce under experimental conditions the changes which are known to take place in streams. In addition, if such an experimental set-up could be established, future studies of streams could be made with greatly reduced expenditure.

Realizing the importance of these experimental studies as an aid to such studies and investigations, the Public Health Service Laboratory for Stream Pollution Investigations, Cincinnati, has been interested continuously in efforts to devise experimental methods which would serve this purpose. The laboratory is fortunately situated for such studies, in that it has ready access to the Ohio River at, and immediately below, Cincinnati. Moreover, as a result of four years of intensive study of this river, during which time bacteriological examinations at successive cross-sections were made, we have fairly good information on the rate of bacterial purification which actually takes place in the river between Cincinnati and Louisville. This stretch of the river represents a distance of 130 river miles, with times of

* Data for comparative purposes are now available which show definitely the course of natural purification and bacterial death rates in two sewage-polluted streams: "A Study of the Pollution and Natural Purification of the Ohio River (*Public Health Bulletin* No. **143**), and "A Study of the Pollution and Natural Purification of the Illinois River" (*Public Health Bulletin* No. **171**). While this tendency of the bacteria to decrease in numbers consistently and rapidly is generally observed in streams, it is not invariably true, for in the Ohio River at Cincinnati following the introduction of Cincinnati sewage, there was an apparent tendency for the bacteria to increase in numbers for several hours (*Public Health Bulletin* **143**, p. 271, *et seq.*).

flow varying from one and one-half up to eight or ten days. Therefore, when samples of water are collected from the Ohio River in this vicinity and observed under experimental conditions, the changes observed may be compared with those known to take place under the same conditions of examination in the same body of water remaining in the stream.

In an attempt to develop methods for studying natural purification on an experimental scale, several series of experiments have been made. For the greater part of the studies, water from the Ohio River at or below Cincinnati has been used. In all cases an attempt has been made to take into consideration and to determine the influence of the various factors which might affect the course of bacterial purification.

Studies of Changes in Bacterial Numbers Occurring in Samples Stored in the Laboratory.—Considerable attention has been devoted from time to time, since the inauguration of stream pollution studies by the Public Health Service, to the nature and extent of changes in bacterial numbers occurring in samples of polluted water stored under various conditions of laboratory environment. The most extensive series of such observations has been made on samples collected from various sources and stored in glass containers, in the dark, at three temperatures, 10°, 20° and 37° C. The first study of this kind was conducted concurrently with the field investigations of the pollution and natural purification of the Ohio River. Later, as opportunity afforded, observations were made on samples from numerous sources, stored under various conditions of environment and subjected to different methods of treatment at the beginning of and during the storage period, in an effort to ascertain the factors that are responsible for or at least modify, the normal changes in bacterial numbers during the storage period.

Source and Nature of Samples.—This study extended over a period of one year from November to October, inclusive, and comprised an examination of 166 samples from four distinct sources, as follows:

(1) Station 475* of the Ohio River, which is below all sewer outlets of the metropolitan district of Cincinnati and above Ohio River Dam No. 37. Samples were taken at three established points on this cross-section of the river and composited in the laboratory to furnish the sample from this source.

(2) Station 598* of the Ohio River, located above the sewer outlets of Louisville, Kentucky. Samples from this source were also composites made from portions collected from three separate sampling points on the cross-section, and are representative of waters from a polluted stream that has been subjected to natural purification processes during a flow of 130 river miles.

(3) Mill Creek, a comparatively small stream draining a densely popu-

* Miles from Pittsburgh.

lated watershed near Cincinnati and receiving considerable volumes of sewage and varied industrial wastes.

(4) Walnut Street sewer in Cincinnati, a combined sewer serving a representative residential and business district of the city and discharging a mixture of domestic sewage, industrial waste and street wash.

Laboratory Methods.—The samples from (1), (3) and (4) were delivered to the Cincinnati Laboratory for examination, while those from (2) were examined at a branch laboratory located at Louisville, Kentucky. The technique employed and the media used were exactly the same in both places. The methods of collection and examination were similar in all respects to those of the Ohio River Investigation studies described in detail in *Public Health Bulletin* No. **143,** pages 336–341.* The only deviation from the uniform method of treatment at the two laboratories was that, at Louisville, no samples were stored at 10° C. as no storage chamber of this temperature was available.

At no time did more than two hours intervene between the collection of the sample and the initial examination; usually the time interval was less than one hour. As soon as the rather large sample was received in the laboratory, it was thoroughly agitated and three equal portions of approximately 200 cc. each were poured out into three sterile bacteriological sample bottles. The initial examination was then made from each of these three portions, after which one was placed in each of three incubators maintained at temperatures of 10°, 20° and 37° C., respectively. It is appreciated that the initial temperature of the sample varied in some degree from the temperature of storage and that a short period would be required under such conditions for the sample to become adjusted to the temperature of its new environment. However, it was considered preferable to allow this adjustment to take place gradually, rather than to expose the sample to a sudden change.

Every effort was made to maintain the storage temperature as constant as possible. The maximum variations observed in the 10-degree Centigrade incubator were ±2° C.; for the 20-degree incubator the variation was ±1° C. and for the 37-degree incubator ±0.5° C.

The bacteriological examinations made comprised total counts on gelatin plates incubated for 48 hours at 20° C. and on agar plates incubated for 24 hours at 37° C., and Coli-aerogenes group determinations as described in *Public Health Bulletin* No. **143.** These examinations were made at definite intervals. At Cincinnati these periods were: at the start and after 4, 8 and 20 hours, and after 1, 2, 4, 6, 13 and 40 or more days of storage. Up to and including the 6th day, the examinations were made at the exact

* "A Study of the Pollution and Natural Purification of the Ohio River. II. Report on Surveys and Laboratory Studies," *Public Health Bulletin* No. **143** (July, 1924), Treasury Department, U. S. Public Health Service, Washington, D. C.

hour interval. The 40-day period was not observed so closely as the results obtained were not at all critical. After March 8 the examination at the end of 4 days was omitted and one at the end of 3 days substituted. The 20-hour and 40-day periods were omitted at the Louisville laboratory and the 13-day period changed to one of 15 days.

TABLE I

AVERAGE RESULTS OF BACTERIOLOGICAL EXAMINATIONS OF STORED SAMPLES OF OHIO RIVER WATER FROM SECTION 475

Period of Storage	Average of 21 Samples of Winter Period Stored at: 10° C.	20° C.	37° C.	Average of 25 Samples of Summer Period Stored at: 10° C.	20° C.	37° C.	Average of 46 Samples of Entire Period Stored at: 10° C.	20° C.	37° C.
				A. Gelatin Counts, 48 Hours, 20° C.					
				Bacteria per Cubic Centimeter					
0 Hrs.	22,900	23,000	20,000	98,400	99,000	110,000	72,000	63,500	69,100
4	26,100	41,900	38,000	111,100	158,000	231,000	71,500	104,000	143,000
8	31,400	104,500	70,500	107,300	241,000	326,000	71,900	177,000	210,000
20	92,000	177,800	112,000	151,000	310,000	283,000	123,500	248,000	205,000
24	84,100	171,000	87,700	184,000	306,000	183,000	138,800	245,000	141,000
48	99,200	56,000	32,300	265,000	176,000	30,000	196,500	122,000	31,100
72	45,200	31,000	13,000	272,000	83,200	16,100	230,000	69,800	15,300
96	91,200	21,500	8,130	.....	.....	.....	.....	.....	.....
6 Days	33,400	11,300	6,360	109,000	25,500	7,890	74,400	19,100	7,200
13	12,200	5,220	1,130	30,800	15,500	870	22,800	11,000	980
40+	3,600	1,970	676	9,540	5,100	567	6,730	3,520	633
				B. Agar Counts, 24 Hours, 37° C.					
0 Hrs.	9,660	8,940	5,870	97,500	96,400	92,000	55,500	54,600	51,800
4	11,100	21,800	21,900	137,000	174,000	291,000	76,600	99,600	152,000
8	14,500	56,800	40,100	134,000	260,000	375,000	78,400	164,000	218,000
20	32,300	98,900	81,000	201,000	382,000	437,000	120,300	244,000	267,000
24	24,300	102,000	68,800	230,000	320,000	179,000	132,000	216,000	128,000
48	41,600	24,600	27,200	245,500	152,000	30,200	148,000	90,000	28,800
72	21,500	10,100	13,100	273,000	64,000	19,400	223,000	50,500	12,700
96	46,800	8,300	9,170	.....	.....	.....	.....	.....	.....
6 Days	13,500	5,400	8,450	108,000	25,100	6,980	62,800	15,700	7,670
13	3,440	2,500	1,100	20,500	14,300	1,200	12,400	8,620	1,150
40+	1,010	900	595	5,900	4,130	794	3,560	2,580	696
				C. Coli-Aerogenes Group					
0 Hrs.	147	383	537	2508	2188	2152	1430	1364	1415
4	147	151	241	1864	2112	1824	1080	1217	1102
8	207	156	344	2328	2984	2184	1390	1693	1374
20	155	207	74	2908	2980	1392	1651	1714	808
24	155	228	199	1432	2512	593	849	1470	422
48	95	35	64	1432	1216	132	822	677	103
72	22	43	15	2512	806	49	1395	477	32
96	92	8	5.8	..	..	.....	..	.....	.....
6 Days	21	8.2	2.2	888	104	23	492	60	14
13	10	3.8	2.4	187	53	1.2	106	30	1.8
40+	3	1.7	0.3	61	11	1.3	35	7	0.8

NOTE: Winter period comprises samples collected from November to April. Summer period comprises samples collected from May to October.

Presentation of Data.—Because of the considerable number of individual analyses, the results are presented here in the form of averages* of the gelatin, agar and Coli-aerogenes group determinations on the samples from each source and are further divided into seasonal periods of winter and summer. These averages are expressed in terms of the actual numbers of bacteria determined. The mean numbers of the Coli-aerogenes group organisms per cc. are expressed in terms of the "*B. coli* index" computed according to the procedure described in "Standard Methods of Water Analysis, 1917." In Table I are presented these average data of samples

TABLE II

AVERAGE RESULTS OF BACTERIOLOGICAL EXAMINATIONS OF STORED SAMPLES OF OHIO RIVER WATER FROM SECTION 598

Period of Storage	Average of 21 Samples of Winter Period Stored at: 20° C.	37° C.	Average of 7 Samples of Summer Period Stored at: 20° C.	37° C.	Average of 28 Samples of Entire Period Stored at: 20° C.	37° C.
	A. Gelatin Counts, 48 Hours, 20° C.					
	Bacteria per Cubic Centimeter					
0 Hrs.	24,200	24,200	7,860	7,870	20,100	20,100
4	32,500	37,800	16,100	39,900	28,400	38,300
8	60,000	195,000	30,000	411,000	52,800	247,000
24	285,000	1,110,000	471,000	1,010,000	330,000	1,130,000
48	145,000	311,600	535,000	192,000	246,000	281,000
96	59,900	59,800	193,000	32,900	93,200	53,300
6 Days	36,100	33 800	77 800	22,000	47,600	31,000
15	24,500	13,100	22,400	3,900	23,200	11,100
	Average of 22 Samples		Average of 7 Samples		Average of 29 Samples	
	B. Agar Counts, 24 Hours, 37° C.					
0 Hrs.	3,640	3,640	3,710	3,710	3,650	3,650
4	5,820	12,300	5,510	31,400	5,740	16,900
8	13,400	184,000	17,700	440,000	14,400	245,000
24	41,400	1,410,000	290,000	1,210,000	101,000	1,360,000
48	31,900	431,000	306,000	205,000	98,100	377,000
96	11,400	81,500	104,000	34,500	33,500	70,100
6 Days	7,220	41,900	35,400	23,900	14,000	37,500
15	5,300	8,200	14,100	1,720	7,430	6,630
	C. Coli-Aerogenes Group					
0 Hrs.	38	38	61	61	44	38
4	91	91	23	34	74	77
8	49	144	60	190	52	155
24	267	198	36	190	209	196
48	132	66	36	30	108	57
96	7.1	10	8.7	3.4	7.5	11.1
6 Days	3.5	2.1	6.1	2.0	4.2	2.1
15	2.0	0.46	3.6	0.34	2.4	0.43

* The detailed analytical data are on file at the Stream Pollution Investigation Station, U. S. Public Health Service, Cincinnati, Ohio.

from Station 475, Ohio River, in Table II similar data are given for samples from Station 598, Ohio River, and Tables III and IV contain the averages of analyses of samples from Mill Creek and Walnut Street sewer, respectively. In computing these averages, the results of the examination of individual samples for corresponding periods and temperatures of storage were added together and divided by the number of individual determinations for the period. Wherever the initial count or more than one count for any period other than the initial was missing from a series, the results

TABLE III

AVERAGE RESULTS OF BACTERIOLOGICAL EXAMINATIONS OF STORED SAMPLES OF SEWAGE FROM MILL CREEK

Period of Storage	Average of 22 Samples of Winter Period Stored at: 10° C.	20° C.	37° C.	Average of 24 Samples of Summer Period Stored at: 10° C.	20° C.	37° C.	Average of 46 Samples of Entire Period Stored at: 10° C.	20° C.	37° C.
				A. Gelatin Counts, 48 Hours, 20° C.					
				Bacteria per Cubic Centimeter (in Thousands)					
0 Hrs.	940.0	874.0	1,040.0	4,070.0	4,410.0	4,160.0	2,573.0	2,590.0	2,670.0
4	1,690.0	2,600.0	3,320.0	6,170.0	7,060.0	6,830.0	4,035.0	4,930.0	5,160.0
8	2,060.0	3,830.0	6,530.0	5,430.0	6,910.0	6,650.0	3,822.0	5,430.0	6,590.0
20	4,690.0	6,020.0	5,460.0	6,430.0	7,650.0	2,190.0	5,600.0	6,860.0	3,760.0
24	4,310.0	5,310.0	2,210.0	6,350.0	6,020.0	857.0	5,237.0	5,680.0	1,510.0
48	4,920.0	1,360.0	343.0	6,550.0	1,970.0	267.0	6,030.0	1,680.0	303.0
72	478.0	209.0	52.1	6,540.0	736.0	89.9	4,815.0	780.0	80.1
96	901.0	429.0	84.5	.....	.....	.....	.....	.....	.....
6 Days	456.0	165.0	37.5	2,120.0	265.0	25.3	1,340.0	218.0	31.0
13	167.0	58.0	4.1	234.0	56.9	5.9	203.0	57.4	5.0
41+	59.4	23.2	0.4	30.4	28.3	0.9	44.2	25.9	0.6
				B. Agar Counts, 24 Hours, 37° C.					
0 Hrs.	513.0	820.0	808.0	8,360.0	8,150.0	8,310.0	4,770.0	4,640.0	4,700.0
4	600.0	2,190.0	3,770.0	12,300.0	12,460.0	14,860.0	6,670.0	7,550.0	9,440.0
8	948.0	3,080.0	6,380.0	11,200.0	14,920.0	13,970.0	6,550.0	9,260.0	10,340.0
20	2,800.0	5,010.0	5,660.0	17,700.0	16,080.0	3,420.0	10,520.0	10,800.0	4,520.0
24	2,230.0	4,230.0	2,190.0	13,800.0	13,650.0	1,880.0	8,420.0	9,140.0	2,030.0
48	2,130.0	785.0	399.0	9,700.0	2,380.0	224.0	6,240.0	1,620.0	308.0
72	329.0	160.0	51.3	11,000.0	907.0	104.0	8,404.0	720.0	90.7
96	415.0	311.0	89.6	.....	.....	.....	.....	.....	.....
6 Days	220.0	100.0	32.9	2,920.0	253.0	39.5	1,683.0	180.0	36.4
13	94.9	33.1	5.4	192.0	69.2	7.6	148.0	51.9	6.5
41+	28.1	8.7	0.6	19.8	28.2	1.7	23.8	18.4	1.2
	Average of 21 Samples			Average of 25 Samples			Average of 46 Samples		
				C. Coli-Aerogenes Group					
0 Hrs.	10.8	15.5	14.7	179.0	233.0	183.0	102.0	134.0	106.0
4	7.8	9.5	66.6	262.0	622.0	305.0	146.0	342.0	196.0
8	14.3	22.8	103.0	309.0	233.0	233.0	174.0	137.0	174.0
20	75.9	42.1	278.0	190.0	266.0	88.5	138.0	164.0	175.0
24	18.1	88.8	175.0	122.0	186.0	37.7	74.4	142.0	100.3
48	22.0	32.2	18.4	258.0	53.2	13.5	150.0	43.6	15.7
72	4.3	3.2	4.0	135.0	44.6	4.2	78.0	34.0	5.8
96	11.9	32.5	10.2	..	..	..	..	..	..
6 Days	7.5	3.5	0.4	29.8	13.9	0.5	19.6	9.2	0.4
13	1.7	1.3		2.5	4.2		2.1	2.9	
41+	0.6	0.1		0.7	0.3		0.7	0.2	

TABLE IV

AVERAGE RESULTS OF BACTERIOLOGICAL EXAMINATIONS OF STORED SAMPLES OF SEWAGE FROM WALNUT STREET SEWER

Period of Storage	Average of 21 Samples of Winter Period Stored at: 10° C.	20° C.	37° C.[a]	Average of 21 Samples of Summer Period Stored at: 10° C.	20° C.[a]	37° C.[b]	Average of 42 Samples of Entire Period Stored at: 10° C.	20° C.[c]	37° C.[d]
A. Gelatin Counts, 48 Hours, 20° C.									
Bacteria per Cubic Centimeter (in Thousands)									
0 Hrs.	2,345.0	2,430.0	2,150.0	2,320.0	2,270.0	2,300.0	2,330.0	2,350.0	2,230.0
4	3,430.0	5,210.0	11,200.0	4,430.0	9,570.0	14,600.0	3,990.0	7,440.0	12,900.0
8	5,801.0	17,400.0	21,200.0	6,560.0	18,100.0	16,100.0	7,090.0	17,700.0	18,600.0
20	18,370.0	33,600.0	14,500.0	12,400.0	37,100.0	11,000.0	16,200.0	33,400.0	12,700.0
24	22,900.0	34,100.0	12,100.0	16,600.0	35,300.0	10,300.0	28,700.0	34,700.0	11,200.0
48	36,100.0	27,000.0	4,400.0	32,500.0	28,800.0	1,640.0	34,200.0	27,900.0	2,990.0
72	44,700.0	21,400.0	3,760.0	36,200.0	11,500.0	800.0	44,400.0	14,100.0	1,620.0
96	35,200.0	7,490.0	1,070.0	.....	.....	.....	.....	.....	.....
6 Days	23,500.0	7,310.0	595.0	45,600.0	2,360.0	217.0	35,100.0	4,720.0	401.0
13	7,940.0	1,690.0	42.6	5,380.0	553.0	32.3	7,510.0	1,100.0	37.0
41+	1,260.0	95.3	1.5	213.0	91.3	2.5	740.0	93.3	2.1
B. Agar Counts, 24 Hours, 37° C.									
0 Hrs.	1,900.0	1,870.0	1,830.0	3,150.0	3,190.0	2,970.0	2,630.0	2,540.0	2,410.0
4	2,880.0	4,320.0	12,000.0	6,200.0	13,300.0	24,800.0	4,540.0	8,790.0	18,400.0
8	4,450.0	11,600.0	21,200.0	8,320.0	21,900.0	19,900.0	6,520.0	16,900.0	20,600.0
20	13,260.0	26,200.0	15,200.0	13,000.0	33,400.0	12,300.0	13,100.0	29,800.0	13,800.0
24	14,150.0	24,400.0	12,000.0	14,500.0	35,900.0	12,000.0	23,300.0	30,300.0	12,000.0
48	20,600.0	20,100.0	5,500.0	21,700.0	19,900.0	2,470.0	22,100.0	20,000.0	3,950.0
72	23,600.0	12,400.0	4,800.0	31,200.0	10,500.0	1,380.0	29,200.0	11,000.0	2,290.0
96	20,900.0	6,040.0	1,360.0	.....	.....	.....	.....	.....	.....
6 Days	16,300.0	3,650.0	1,250.0	21,700.0	2,590.0	665.0	19,900.0	3,110.0	951.0
13	5,270.0	700.0	78.3	3,500.0	728.0	88.0	4,440.0	714.0	83.7
41+	539.0	77.6	8.5	258.0	126.0	4.1	399.0	103.0	6.2
	Average of 21 Samples			Average of 24 Samples			Average of 45 Samples		
C. Coli-Aerogenes Group									
0 Hrs.	52.4	104.0	109.0	149.0	156.0	205.0	104.0	132.0	160.0
4	147.0	156.0	297.0	306.0	2,120.0	1,940.0	232.0	1,200.0	1,170.0
8	151.0	396.0	2,110.0	269.0	2,280.0	3,960.0	214.0	1,400.0	3,320.0
20	649.0	2,500.0	2,630.0	1,370.0	5,460.0	4,260.0	1,030.0	4,800.0	3,500.0
24	314.0	1,990.0	4,730.0	1,290.0	4,750.0	4,260.0	836.0	3,460.0	4,480.0
48	1,548.0	1,690.0	520.0	2,280.0	4,300.0	381.0	1,940.0	3,080.0	446.0
72	2,775.0	1,680.0	426.0	2,940.0	1,300.0	126.0	2,360.0	894.0	201.0
96	2,250.0	362.0	202.0	.....	.....	.....	.....	.....	.....
6 Days	953.0	207.0	46.9	1,860.0	224.0	66.2	1,440.0	216.0	57.2
13	216.0	40.0	0.7	227.0	51.2	4.4	222.0	46.0	2.7
41+	16.8	13.6		91.8	5.7		56.0	9.4	

[a] Average of 22 samples. [b] Average of 23 samples. [c] Average of 43 samples. [d] Average of 45 samples.

from that sample were omitted from all totals. As observations were not made at both the 72- and 96-hour periods throughout the entire year, but at only one or the other of these times, the averages obtained for these periods are of less weight than are those for the other times of storage.

Using the 20° C. bacterial plate counts from samples stored at all three temperatures as recorded in Tables I, II, III and IV, Figures 1, 2, 3 and 4

have been prepared. In preparing these charts, the bacteria in terms of per cent of the initial count have been plotted against time of storage in hours. For the sake of brevity the 37° C. counts and the Coli-aerogenes results have not been presented graphically. The bacterial results obtained from the 37° C. plate counts are fairly accurately represented by the 20° C. results regardless of the temperature of storage of the sample.

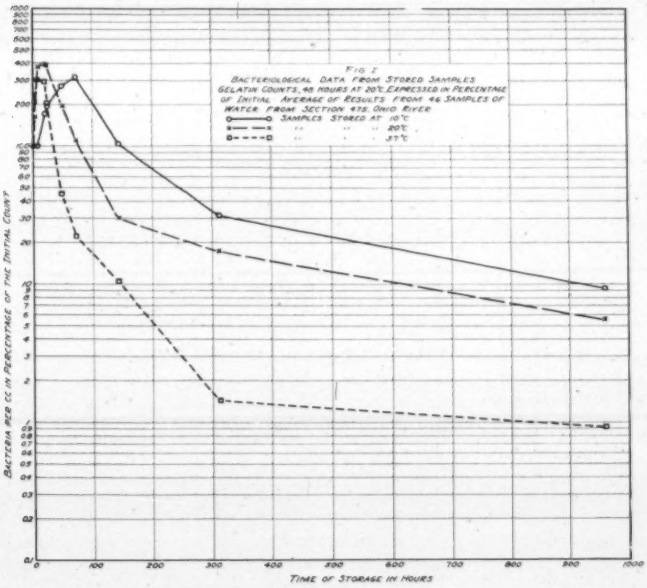
FIG. 1
BACTERIOLOGICAL DATA FROM STORED SAMPLES
GELATIN COUNTS, 48 HOURS AT 20°C. EXPRESSED IN PERCENTAGE
OF INITIAL AVERAGE OF RESULTS FROM 46 SAMPLES OF
WATER FROM SECTION 475 OHIO RIVER
SAMPLES STORED AT 10°C
" " " 20°C
" " " 37°C
BACTERIA PER CC IN PERCENTAGE OF THE INITIAL COUNT
TIME OF STORAGE IN HOURS

Discussion of Results.—The data of these tables and figures disclose the occurrence of significant changes in the bacterial numbers during the storage of the samples. With but three exceptions* (and the results from

* Three exceptions to this are noted as follows:

(*a*) One sample collected from Station 475 Ohio River on September 27, in portions stored at 10 and 37° C., showed a decrease in bacterial numbers from the start on the gelatin plate counts. The 37° C. plates made from all portions showed the characteristic increase. The Coli-aerogenes group apparently increased in the portion stored at 37° C. but not in those stored at 10 and 20° C.

(*b*) One sample from Mill Creek collected on March 29 showed a continuous decrease in bacterial numbers on gelatin plates from all portions and also on the agar

these exceptions were not consistent on the different plating media), the bacteria increased following the beginning of storage in all of the 166 samples and at all three temperatures regardless of the condition of the sample at the time of collection. The maximum numbers observed varied in extent with the source of the samples and with the temperature of storage. The maximum numbers were reached at different periods which varied with the temperature of storage. Immediately following the time the maximum count was observed, a rapid and consistent decrease occurred in all portions of the samples at all temperatures. Both the rate

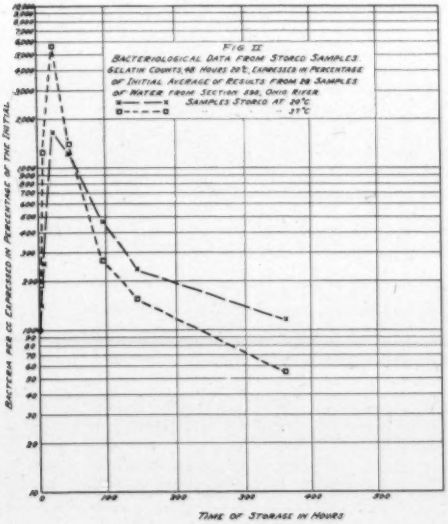
FIG. II
BACTERIOLOGICAL DATA FROM STORED SAMPLES.
GELATIN COUNTS, 48 HOURS 20°C, EXPRESSED IN PERCENTAGE OF INITIAL AVERAGE OF RESULTS FROM 28 SAMPLES OF WATER FROM SECTION 330, OHIO RIVER.
SAMPLES STORED AT 20°C
37°C
BACTERIA PER CC EXPRESSED IN PERCENTAGE OF THE INITIAL
TIME OF STORAGE IN HOURS

and the extent of this decrease apparently varied with the temperature of storage.

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plates from the portion stored at 37° C. The Coli-aerogenes index increased in the portion stored at 10° C., but not in the other two.

(*c*) A third sample obtained from Mill Creek on July 26 showed a decrease from the start as determined by the gelatin plates made from the portion stored at 37° C. All other plate counts from this sample showed the usual increase in bacterial numbers. The Coli-aerogenes index increased in the portion of this sample stored at 10° C., but not in those stored at 20° and 37° C. Although these results appeared to be atypical, they were included in the averages.

These facts regarding the increase in bacterial numbers and the maxima observed are illustrated more clearly in Table V where the average initial counts, maximum counts, percentage increase and the average time required to reach the maximum are presented. The extent of multiplication appears to vary between wide limits and may be dependent upon various

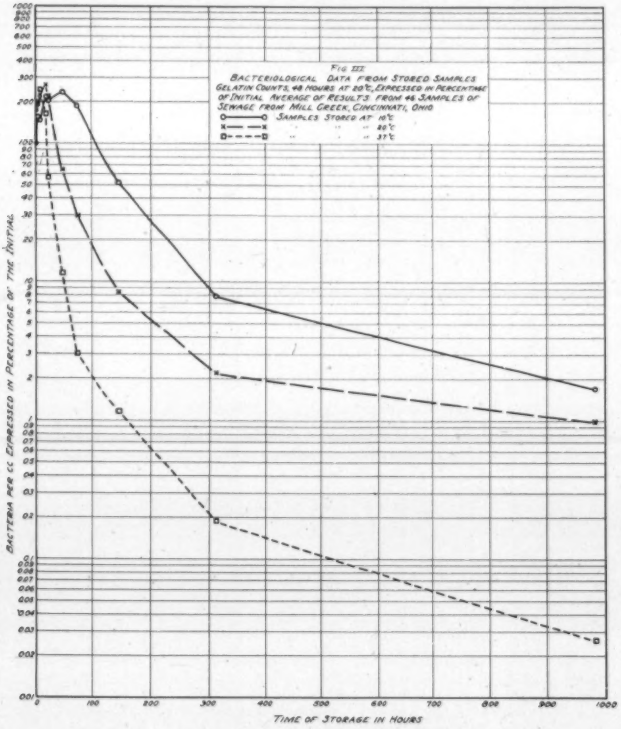
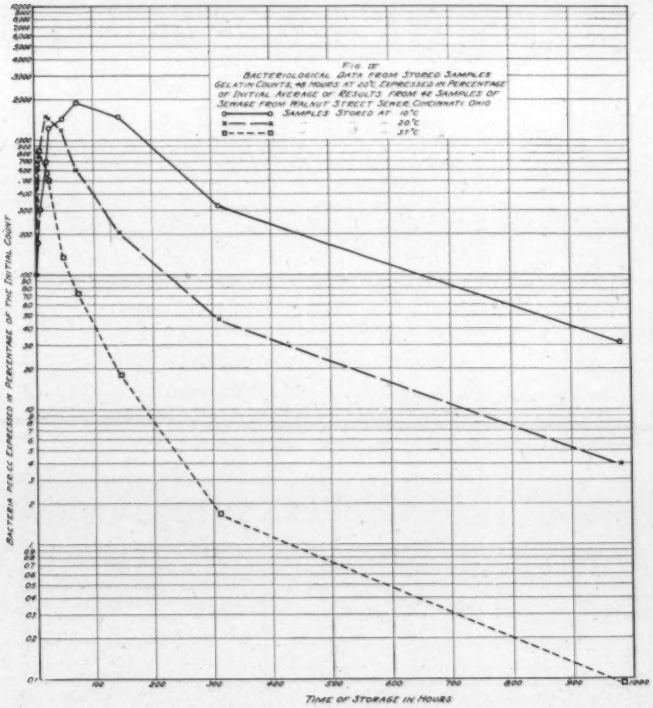


FIG III
BACTERIOLOGICAL DATA FROM STORED SAMPLES
GELATIN COUNTS, 48 HOURS AT 20°C, EXPRESSED IN PERCENTAGE
OF INITIAL AVERAGE OF RESULTS FROM 46 SAMPLES OF
SEWAGE FROM MILL CREEK, CINCINNATI, OHIO
O——O SAMPLES STORED AT 10°C
X—— —X " " " 20°C
□- - -□ " " " 37°C
BACTERIA PER CC EXPRESSED IN PERCENTAGE OF THE INITIAL
TIME OF STORAGE IN HOURS

factors. Considered from the standpoint of the source of the samples, the greatest increases as measured by plate counts were observed in samples from Station 598 of the Ohio River and from Walnut Street sewer, while the minimum increases occurred in samples from Mill Creek. In the case of the Coli-aerogenes group results, the greatest increases also were found in

samples from Walnut Street sewer and the least in samples from Section 475 of the Ohio River. These observations also hold regardless of whether the averages for the winter period, summer period or for the entire period are being considered, although with very few exceptions the average increase was greater in samples from all sources collected during the winter

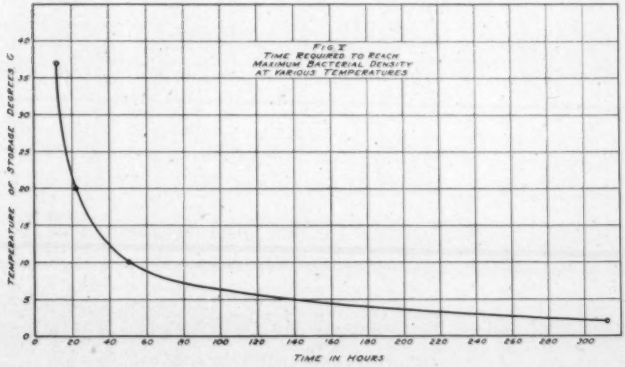


period. Such increases in the bacterial content probably would be expected in samples from Mill Creek and Walnut Street sewer where large amounts of pollution had been recently introduced but they were not expected in samples from Section 598 where extensive natural purification had already occurred.

TABLE V. SUMMARY OF BACTERIOLOGICAL DATA OF STORED SAMPLES FROM ALL SOURCES

Source of Samples	Temperature of Storage (° C.)	Winter Period: Number of Samples	Winter Period: Average Initial Count	Winter Period: Average Maximum Count	Winter Period: Per Cent of Initial	Winter Period: Hours to Reach	Summer Period: Number of Samples	Summer Period: Average Initial Count	Summer Period: Average Maximum Count	Summer Period: Per Cent of Initial	Summer Period: Hours to Reach	Entire Period: Number of Samples	Entire Period: Average Initial Count	Entire Period: Average Maximum Count	Entire Period: Per Cent of Initial	Entire Period: Hours to Reach
A. Gelatin Counts, 48 Hr., 20° C.																
475, Ohio R.	10	21	19,000	79,300	417	31	25	98,400	328,000	334	49	46	63,100	219,400	347	41
	20	21	19,500	120,000	615	21	25	98,800	417,500	423	18	46	63,500	291,000	458	20
	37	21	19,000	112,600	592	20	25	152,000	404,000	266	8	46	67,300	280,000	416	14
598, Ohio R.	20	22	24,100	220,000	913	27	7	7,870	590,700	7,500	41	29	20,100	313,000	1,560	31
	37	22	24,160	1,090,000	4,510	25	7	7,870	1,047,000	13,300	17	29	20,900	1,079,000	5,160	23
Mill Creek	10	21	775,000	5,940,000	765	24	25	4,084,000	8,480,000	208	32	46	2,573,000	7,260,000	282	29
	20	21	687,000	7,120,000	1,040	15	25	4,430,000	9,660,000	218	12	46	2,721,000	8,497,000	312	13
	37	22	831,000	7,860,000	946	13	24	4,220,000	7,720,000	183	6	46	2,671,000	7,782,000	292	9
Walnut St. Sewer	10	21	2,321,000	39,300,000	1,690	79	24	2,341,000	59,000,000	2,520	99	45	2,332,000	49,800,000	2,140	90
	20	21	2,395,000	35,100,000	1,465	22	24	2,295,000	43,000,000	1,890	25	45	2,341,000	39,480,000	1,685	24
	37	21	2,074,000	22,150,000	1,070	12	24	2,360,000	21,360,000	904	9	45	2,226,000	21,730,000	961	10
B. Agar Counts, 24 Hr., 37° C.																
475, Ohio R.	10	21	7,830	30,700	392	31	25	98,000	329,000	336	56	46	56,800	193,000	340	45
	20	21	5,510	61,130	1,110	21	25	95,800	449,000	469	19	46	54,600	272,000	497	20
	37	21	5,870	86,700	1,480	20	25	108,000	593,000	549	10	46	59,100	357,000	603	15
598, Ohio R.	20	22	3,640	42,500	1,170	35	7	3,700	346,000	9,350	34	29	3,650	115,000	3,150	35
	37	22	3,640	1,420,000	39,000	25	7	3,700	1,236,000	33,400	19	29	3,660	1,375,000	37,600	25
Mill Creek	10	21	870,500	3,380,000	388	23	25	8,364,000	18,860,000	226	29	46	4,943,000	11,790,000	239	26
	20	21	513,000	4,806,000	938	17	25	8,140,000	20,230,000	249	17	46	4,660,000	13,186,000	282	17
	37	22	489,000	7,763,000	1,590	14	24	8,010,000	17,510,000	219	7	46	4,575,000	13,063,000	285	10
Walnut St. Sewer	10	21	1,790,000	25,950,000	1,450	80	24	3,210,000	34,500,000	1,075	88	45	2,555,000	30,600,000	1,200	84
	20	21	1,800,000	28,700,000	1,595	22	24	3,190,000	39,200,000	1,230	23	45	2,542,000	34,279,000	1,350	23
	37	21	1,742,000	22,310,000	1,260	12	24	3,000,000	27,200,000	906	7	45	2,414,000	24,923,000	1,030	9
C. Coli-Aerogenes Group																
475, Ohio R.	10	21	147	398	269	5	25	2,510	9,244	368	12	46	1,430	5,200	362	9
	20	21	338	614	183	13	25	2,188	4,960	227	6	46	1,340	2,980	220	9
	37	21	131	529	350	5	25	2,188	3,962	181	2	46	1,260	2,360	187	4
598, Ohio R.	20	22	38	374	984	15	7	61	74	121	1	29	44	302	686	11
	37	22	38	292	769	10	7	61	203	333	5	29	44	270	614	9
Mill Creek	10	21	10,800	95,300	883	21	25	180,000	676,000	376	10	46	102,300	401,900	392	15
	20	21	15,600	104,000	667	9	25	233,200	964,000	413	5	46	138,400	571,000	413	7
	37	22	14,200	374,000	2,640	11	24	183,000	456,000	255	3	46	105,850	418,700	396	7
Walnut St. Sewer	10	21	57,100	3,050,000	5,340	54	24	150,000	4,710,000	3,140	39	45	106,000	3,940,000	3,720	46
	20	21	104,000	4,100,000	3,940	24	24	156,000	7,750,000	4,960	13	45	132,000	6,044,000	4,570	18
	37	21	109,000	5,710,000	5,250	15	24	205,000	6,620,000	3,230	8	45	160,000	6,200,000	3,870	11

The average times required for each of the various groups of samples to reach their maximum bacterial numbers, starting from the beginning of the storage period in each case, are also given in Table V. These times are consistently longest, as might be expected, for samples stored at 10° C., and shortest for those stored at 37° C. The Coli-aerogenes group apparently reach their maximum numbers in a shorter time than the bacteria growing on agar and gelatin. There is, however, a considerable divergence of these time periods for samples from various sources, especially when stored at 10° C. These changing interrelationships would seem to indicate that for samples such as were used in these studies, as the interval between sample collection and bacterial enumeration increases, changes in the ratio of plate counts to the Coli-aerogenes counts must be anticipated. In regard to the time required to reach the maximum in samples



collected in summer, as compared with those of the winter period, this time is consistently shorter for the summer when the samples are stored at 37° C.; for other temperatures of storage the time is not greatly affected by seasonal conditions except perhaps in the case of Coli-aerogenes group results, where in winter samples a longer period is apparently required to attain the maximum.

In general it can be said that the samples stored at 37° C. reached their maximum bacterial density in about 12 hours, those stored at 20° C. in approximately 22 hours, and when stored at 10° C. the time to reach the maximum count was extended to about 50 hours. Greenfield, Elder and McMurray* have shown that at an incubation temperature of 2° C. the

* R. E. Greenfield, A. L. Elder and R. E. McMurray, "Further Studies on the Oxygen Demand Test," *Ind. & Eng. Chem.*, **18**, 1276 (1926).

maximum count occurs on the thirteenth day. The curve indicated by this time-temperature relationship is shown in Figure 5.

To make observations on the possible influence which the magnitude of the initial count might have on the maximum count attained, the data of the gelatin counts were grouped according to the range of the initial count. The group averages of these maximum counts were computed then and from these data the average percentage increase was determined for each group. These percentages are presented in Table VI for the samples from each of the four sources. It will be observed that for each source of samples the maximum increase always occurred in the group with the lowest initial count and, furthermore, that as the initial count became higher, this percentage increase quite consistently declined. The maximum number reached appeared to be definitely limited for the samples from each source regardless of the actual density of bacteria at the time of collection. This suggests that there exists a quite definite upper limit of bacterial density for each type of sample, which in general is not exceeded. This observation is in agreement with the suggestion* that a given food concentration definitely limits the number of bacteria capable of developing in a media.

These results also suggest that the bacterial population of these samples at the time of collection is not at the maximum which the available food supply will support and that under natural conditions some agency tends to keep the bacterial population below this maximum.

TABLE VI

COMPARISON OF PERCENTAGE INCREASES FROM INITIAL COUNTS OF VARIOUS MAGNITUDES

(Gelatin Plate Counts)

Range of Initial Counts	Station 475, Ohio River, Maximum Per Cent of Initial When Stored at: 10° C.	20° C.	37° C.	Station 598, Ohio River, Maximum Per Cent of Initial When Stored at: 20° C.	37° C.	Mill Creek, Maximum Per Cent of Initial When Stored at: 10° C.	20° C.	37° C.	Walnut St. Sewer, Maximum Per Cent of Initial When Stored at: 10° C.	20° C.	37° C.
0– 10,000	970	1410	2210	4130	15100						
10,000– 25,000	894	1320	1160	2270	9770						
25,000– 50,000	579	792	692	770	1460						
50,000– 100,000	522	643	297	1130[a]		5100	8120	8580			
100,000– 200,000	195	134	207			1840	1370	3060			
200,000– 400,000	133	134	121			2990	3160	3390			
400,000– 800,000	115	161	212			862	865	912	3400[a]	3060	2090[a]
800,000–1,600,000						326	341	454	3290	2340	1370
1,600,000–3,200,000						353	528	286	2280	1830	833
Over 3,200,000						170	194	179	1430	1230	818

[a] One result only in this group.

Considering now the period of decline in bacterial numbers which invariably occurred after the maximum had been reached, reference is made

* C. T. Butterfield, *Pub. Health Reports*, **44**, 2865 (1929), Reprint No. 1336.

again to Figures 1, 2, 3 and 4. Observations which were made on the time required for the bacteria to reach a maximum density are equally applicable to the time required for the decline in bacterial numbers to begin. The rate of decrease varied with the temperature of storage, being the most rapid at 37° C., and the slowest at 10° C. Regardless of the source of the samples or the temperature of storage, the rate of decrease was much more rapid during the period immediately following the initiation of the decrease than it was toward the end of the period. The duration of this first period of rapid decrease in bacterial numbers varied with the temperature of storage, continuing for about 4 days at 37° C., 6 days at 20° C. and 13 days at 10° C. Thereafter in each instance the decline in the number of bacteria present was more gradual.

The extent of the bacterial decrease, as measured by the percentage of the initial count remaining, was affected also by the temperature of storage. Without exception the most extensive decreases, in samples from all sources, occurred at 37° C., and the least extensive at 10° C. Considered from the viewpoint of the source of the samples, the greatest decrease in numbers took place in the samples from Mill Creek, the least decrease in the samples from Station 598, while the reductions observed in samples from Station 475 and Walnut Street sewer were of similar magnitude.

If the agent which prevented the bacteria from reaching their maximum population under natural conditions is the same one that produced the rapid decrease in bacterial numbers in the samples after the maximum had been attained, then this agent must have been temporarily restrained or depressed by the change brought about when the sample was removed from its normal environment.

Influence of Various Factors on Bacterial Changes in Stored Samples.—Having established the general tendency of bacteria to increase in numbers in samples of polluted water, regardless of the source of collection, various experiments have been set up from time to time to make observations on some of the factors which might modify or induce this phenomenon. These separate studies necessarily have not been extensive and the results at best can be considered as only roughly indicative of the general effect which these various factors may produce. In these exploratory experiments, consideration has been given to the possible influence of: (1) an air surface (completely filled and partially filled bottles), (2) light (direct and diffused sunlight), (3) agitation, (4) preliminary reduction in bacterial numbers accomplished by centrifuging or by filtering, (5) size of the sample, and (6) the nature of the container.

Observations on the Bacterial Changes in Samples When Stored in Ground Glass Stoppered Bottles: (a) Completely Filled, and (b) Half Full.—Two samples of water were collected from the Ohio River. Immediately on arrival at the laboratory, each sample was shaken thor-

oughly and divided into four parts in clean, sterile, glass-stoppered bottles of 350-cc. capacity. In each case, two of the bottles were filled completely full and two half-full with the sample. The samples thus prepared were stored at 20° C. in the dark and examinations were made after various intervals during the next five days. The results obtained from these samples, expressed in percentages of the initial count, on both 20° C. plates and on 37° C. plates, are given in Table VII.

TABLE VII

OHIO RIVER WATER STORED IN FULL AND PARTLY FULL BOTTLES

Time of Storage, Hours	Gelatin Counts 20° C. for 48 Hours Sample 88 Initial Count 8040 per Cc. Per Cent Remaining in: Full Bottles	Half-full Bottles	Gelatin Counts 20° C. for 48 Hours Sample 89 Initial Count 64,500 per Cc. Per Cent Remaining in: Full Bottles	Half-full Bottles	Agar Counts 37° C. for 24 Hours Sample 88 Initial Count 6450 per Cc. Per Cent Remaining in: Full Bottles	Half-full Bottles	Agar Counts 37° C. for 24 Hours Sample 89 Initial Count 37,000 per Cc. Per Cent Remaining in: Full Bottles	Half-full Bottles
0	100	100	100	100	100	100	100	100
7	152	197			153	146		
17			638	702			365	389
24	254	354			198	359		
31	259	467			118	279		
41			297	350			357	433
48	254	395			236	512		
65			139	158			127	187
72	225	304			157	260		
113			71	51			82	83
120	104	227			81	160		

In the bottles completely full, mixing at the time of sampling was obtained by swirling and inverting the bottle. This method, by previous tests with water containing visible sediment, had been demonstrated to be effective. The half-filled bottles were shaken in the usual manner. The 1-cc. portion withdrawn from the completely filled bottle at each sampling time was replaced with water from the partly filled bottle.

No marked differences are noted between the results from the completely filled and the partially filled bottles. Although the percentage increase is slightly greater in the partially filled bottles in each instance, this difference does not appear to be of sufficient magnitude to be significant. Under both conditions the usual marked bacterial multiplication took place in the stored sample, reaching a maximum between the first and second day and thereafter decreasing.

Observations on the Effect of Light on Bacterial Counts from Stored Samples.—As the elimination of light from our stored samples was a marked change from the environmental condition of the water in the river, these observations on the light factor were made. Ohio River water from the same location was employed. Storage was in the open, with direct exposure to sunlight when the sun was shining. The tests were made

in midsummer. Six different methods of exposure were tried and a companion sample was stored in the dark in the 20° C. incubator. The methods of exposure were as follows: portions of samples, designated "A" and "B" were stored in wide-topped, 5-gallon capacity wooden buckets. In "A" the bucket was only half-filled with the sample, while in "B" it was filled to the brim. This resulted in the "B" sample receiving somewhat more direct light than "A," for during a part of the day portions of "A" were shaded by the side walls of the bucket. In "C" the sample was stored in a 2-liter glass bottle. In "D" a 2-liter portion of the sample was placed in a Pyrex glass flask. The "E" sample container was exactly similar to "D" but this portion was kept in the 20° C. incubator in the dark. In "F" and "H" 18-liter portions were placed in glass carboys, in "F" the carboy was of ordinary glass, while in "H" the glass was Pyrex.

Bacterial counts on agar incubated for 24 hours at 37° C., and on gelatin incubated for 48 hours at 20° C., were made on each sample at frequent intervals. The series was repeated four times with approximately a simi-

TABLE VIII

CHANGES IN BACTERIAL NUMBERS IN SAMPLES OF OHIO RIVER WATER STORED IN CONTAINERS EXPOSED TO LIGHT

Time of Storage, Hours	Type of Container A Bucket Half-full	B Bucket Full	C 2-Liter Glass Bottle	D 2-Liter in Light	E Pyrex Flask in 20° C. Incubator	F 18-Liter Ordinary Glass	H Carboy Pyrex Glass
	1a. Agar Counts, 24 Hours at 37° C.						
	Bacteria per Cubic Centimeter						
0	3,710	3,710	3,710	3,710	3,710	4,360	4,360
5	5,010	3,150	4,420	2,980	3,070	5,350	5,220
22	71,900	47,400	73,100	73,300	17,500	103,000	115,000
29	113,000	49,800	68,600	41,700	15,200	92,300	97,300
46	57,600	29,000	34,200	35,700	15,500	56,000	49,000
53	59,100	44,100	28,500	5,420	12,400	34,200	35,200
70	31,800	37,000	16,900	21,600	5,950	20,200	17,200
96	50,900	20,200	11,900	20,500	3,450	16,300	16,400
118	9,200	7,180	9,520	44,800	3,580	8,500	7,920
142	14,700	9,200	5,050	10,300	2,550	9,550	5,450
	2a. Gelatin Counts, 48 Hours at 20° C.						
0	44,200	44,200	44,200	44,200	44,200	57,200	57,200
5	72,600	43,600	42,400	25,800	38,300	55,000	51,300
22	354,000	194,000	112,000	123,000	147,000	188,000	211,000
29	377,000	246,000	85,600	68,800	97,200	93,200	108,000
46	388,000	203,000	46,700	55,700	67,200	49,800	117,000
53	282,000	184,000	28,900	32,500	59,900	50,800	56,000
70	250,000	135,000	22,000	20,400	25,200	31,400	29,400
96	237,000	126,000	52,300	31,800	31,500	14,900	12,200
118	108,000	67,000	9,350	16,200	11,100	9,950	10,100
142	50,500	26,400	3,150	2,300	12,300	5,900	4,700

lar trend in the results each time. The average results obtained from these four series are presented in Table VIII.

These results indicate that while direct light did alter to a slight extent the course of the bacterial activity in these samples, it did not prevent the initial increase in bacteria ordinarily observed in stored samples. It is probable that with very small samples, which the light would penetrate completely, the effect would be greater. However, this would not stimulate stream conditions. There was no marked difference between the results from samples which received direct light (in the buckets) and those which received light that had passed through either ordinary or Pyrex glass.

Effect of Agitation on Bacterial Counts from Stored Samples.—To ascertain the effect of agitation, comparative studies were made on a sample of sewage. After thorough agitation, the sample was divided into four equal portions of about 1800 cc. each and placed in 2500-cc. glass-stoppered bottles. These four portions were then stored in the dark in the 20° C. incubator and examined bacteriologically at the end of 24 and 72 hours.

From Bottle 1, three 1-cc. portions of sample were carefully withdrawn at each examination, the first portion from just below the surface, the second from mid-depth and the third from just above the bottom of the bottle. The contents of this bottle were not disturbed at any time. Before removing portions for examination from Bottle 2, the contents were shaken 25 times in the usual manner, while Bottle 3 was similarly shaken 50 times and Bottle 4 75 times. The results of these observations are given in Table IX.

TABLE IX

CHANGES IN BACTERIAL NUMBERS IN STORED SEWAGE SAMPLES WITH AND WITHOUT AGITATION

Time of Storage in Hours	Percentage of Initial Count Remaining in Sample From: Bottle 1. No Agitation			Bottle 2 Agitated 25 Times	Bottle 3 Agitated 50 Times	Bottle 4 Agitated 75 Times
	Top	Mid-depth	Bottom			
A. Gelatin Plates Incubated 48 Hours at 20° C. Initial Count 3,220,000 per Cubic Centimeter						
0	100	100	100	100	100	100
24	658	845	668	820	876	926
72	360	861	553	528	...	...
B. Agar Plates Incubated 24 Hours at 37° C. Initial Count 1,090,000 per Cubic Centimeter						
0	100	100	100	100	100	100
24	1640	1480	1295	1840	2150	2410
72	935	1340	955	1505	...	

These results show that the usual increase in bacterial numbers was observed in both the shaken and quiescent portions. There was relatively

little difference between the results obtained from portions taken from the top, middle and bottom of the stored sample, which would indicate that sedimentation or stratification of the bacteria, if it occurred, did not affect the results to any appreciable extent. Shaking of the samples prior to withdrawing portions for analysis appeared to increase slightly the numbers of colonies developing on both the gelatin and agar plates.

Effect of Artificial Reduction of Bacterial Numbers on Later Increase.—Limited studies were made on the effect of reducing, by artificial means, the bacterial content of portions of samples and comparing the tendency to increase occurring in the treated and untreated portions when stored. Centrifuging and filtration through paper or cotton were the methods employed for reducing the bacteria in the original samples. It must be borne in mind that such procedures undoubtedly altered more than the bacterial content of the samples. Other larger organisms and amorphous matter were probably more extensively affected. In the first trial a sample of Ohio River water, after thorough mixing, was divided into two portions, one of which was centrifuged at high speed for 20 minutes. This centrifuged portion was then divided into two equal parts by siphoning off the supernatant half, after which all three portions were stored at 20° C. The usual tendency of the bacteria to increase was observed in all portions.

TABLE X

CHANGES IN BACTERIAL NUMBERS IN UNTREATED AND CENTRIFUGED SAMPLES OF OHIO RIVER WATER

Time of Storage	Results in Terms of Percentages of Initial Count: Portion Stored Without Treatment	Portion Centrifuged for 15 Minutes: Bottom Half	Portion Centrifuged for 15 Minutes: Top Half
A. Gelatin Plates Incubated for 48 Hours at 20° C. Initial Count	(22,200 per Cc.)	(154,000 per Cc.)	(5900 per Cc.)
0 Hrs.	100	100	100
18	469	650	16,900
24	645	650	16,900
42	1100	1510	46,000
72	820	734	11,000
96	825	643	7,120
6 Days	383	332	4,370
B. Agar Plates Incubated for 24 Hours at 37° C. Initial Count	(14,200 per Cc.)	(35,000 per Cc.)	(4900 per Cc.)
0 Hrs.	100	100	100
18	238	2570	18,400
24	317	2570	20,400
42	872	3660	48,800
72	696	4600	22,200
96	585	3720	8,250
6 Days	500	1260	632

In fact, the increases were more marked in the centrifuged portions, particularly in the supernatant.

The above experiment was carefully repeated, using the same procedure except that the centrifuge was operated for 15 minutes only instead of 20 minutes as in the previous test. The results obtained are presented in Table X.

These results indicate that the bacteria increased in both the centrifuged and the untreated portions of the samples. In the centrifuged portions, the supernatant showed a reduced initial count and the bottom portions an increased initial, as would be expected.

It is noted also that the bacterial increases and the maxima in the centrifuged portions of the samples are generally much greater and are sustained longer than those in the untreated portions. This would suggest that the deterrent of bacterial growth had been adversely affected by the centrifuging process. The maximum bacterial density was approximately the same in both portions of the centrifuged sample, although the percentage increase in the supernatant part was much greater.

Further studies on the effect of the reduction of bacterial numbers in samples on the subsequent bacterial activity were made by filtering portions of the sample through hard filter paper or cotton wool. Two samples of Ohio River water were collected and each divided into two equal portions, one portion of each sample being filtered through hard filter paper. All portions were stored in glass bottles in the dark at 20° C. Bacterial counts obtained after various intervals are shown in Table XI.

TABLE XI

COMPARATIVE CHANGES IN STORED PORTIONS OF FILTERED AND UNFILTERED SAMPLES OF OHIO RIVER WATER

	Results Expressed in Percentage of Initial Count			
	Gelatin Plates, 48 Hrs. at 20° C.[a]		Agar Plates, 24 Hrs. at 37° C.	
Time of Storage in Hours	Unfiltered Initial Count, 43,000 per Cc.	Filtered Initial Count, 1600 per Cc.	Unfiltered Initial Count, 2240 per Cc.	Filtered Initial Count, 266 per Cc.
0	100	100	100	100
5	...	...	291[a]	156[a]
18	209	3370	200[a]	2480[a]
24	295	4560	464	4060
48	181	8050	400	5720
72	128	6930	351	5410
77	...	...	447[a]	2590[a]
96	...	...	468[a]	1330[a]
120	...	...	323[a]	1540[a]
144	27	2630	225	2440

[a] One sample only.

A similar study was made of a sample of sewage. The sample was divided into three parts: one was untreated, another was filtered through cotton wool and the third portion was filtered through hard filter paper. All portions of the sample were then stored in the dark at 20° C., and examined bacteriologically with the results given in Table XII.

TABLE XII

BACTERIAL CHANGES IN FILTERED AND UNFILTERED PORTIONS OF A SEWAGE SAMPLE

Time of Storage in Hours	Counts from Agar Plates, 24 Hrs. at 37° C. Results in Percentage of Initial Count		
	Untreated Initial Count 1,040,000	Filtered through Cotton, Initial Count 530,000	Filtered through Paper, Initial Count 37,700
0	100	100	100
5	185	252	21
24	963	3740	43,800
48	1070	3560	122,000
72	740	2620	152,000
96	635	1110	22,000
144	337	887	3,160

While the data of these observations, concerning the effect of centrifuging and filtering on the subsequent bacterial behavior in stored samples, are too meager to be conclusive, they do seem to indicate that if the balance existing in the sample is disturbed by centrifuging or by filtering, more extensive bacterial increases will occur, and that the greater maxima will be sustained longer when the preliminary removal is probably more nearly complete. An assumption of the elimination or diminution of organisms or substances inimical to bacteria and their growth would explain this phenomenon.

Studies on the Effect of the Size of the Container on the Bacterial Increase in Stored Samples.—Various comparative experiments have been conducted to ascertain if the size of container had any appreciable effect on the bacterial increases observed. In three series of observations, samples of Ohio River water were collected and divided into two portions each, one of which, 20 liters in amount, was placed in a 22-liter glass carboy, and another portion of 200 cc. in a 250-cc. glass bottle. Both portions were then stored in the 20° C. incubator. Bacterial counts were made at various intervals and the averaged results are presented in Table XIII.

There is good agreement between the results obtained from the large and small portions. This indicates that, in these instances at least, the size of the container was not a factor in causing the increase of bacterial numbers during storage.

TABLE XIII

BACTERIAL CHANGES IN LARGE AND SMALL PORTIONS OF THE SAME SAMPLES

Time of Storage in Hours	Results in Percentage of Initial Count: Gelatin Plates, 48 Hrs. at 20° C. 22-Liter Carboy, Initial Count 51,200 per Cc.	Gelatin Plates, 48 Hrs. at 20° C. 250 Cc. Bottle, Initial Count 48,900 per Cc.	Agar Plates, 24 Hrs. at 37° C. 22-Liter Carboy, Initial Count 19,600 per Cc.	Agar Plates, 24 Hrs. at 37° C. 250 Cc. Bottle, Initial Count 18,700 per Cc.
0	100	100	100	100
5	77	89	113	156
24	1730	1520	1900	2730
48	1530	1910	1680	1640
72	754	595	1140	1180
96	324	303	459	540
144	..	59	..	115

Observations on the Influence of the Nature of the Container.—To determine the influence of the nature of the container on the bacterial increases observed in stored samples, a series of eleven samples of sewage were collected. One portion of each sample was stored in a plain glass bottle of 250-cc. capacity and the other portion was placed in a similar bottle, the interior of which was coated thoroughly with paraffin. All samples were stored at 20° C. and periodically examined to determine the bacterial density, both of organisms growing on agar plates at 37° C. and of the Coli-aerogenes group. The average results of these observations are given in Table XIV.

TABLE XIV

COMPARATIVE CHANGES IN SEWAGE SAMPLES STORED IN GLASS BOTTLES LINED WITH PARAFFIN AND IN SIMILAR BOTTLES UNLINED

Time of Storage, Days	Results in Terms of Percentage of Initial Count: Samples in Glass Bottles: Agar Plates, 24 Hrs. at 37° C., Initial 1,620,000 per Cc.	Samples in Glass Bottles: Coli-aerogenes, Initial Determination 160,000 per Cc.	In Paraffin-Lined Bottles: Agar Plates, 24 Hrs. at 37° C., Initial 1,670,000 per Cc.	In Paraffin-Lined Bottles: Coli-aerogenes, Initial Determination 180,000 per Cc.
0	100	100	100	100
1	1020	1130	1000	2050
2	845	444	862	833
3	456	156	550	139
4	303	294	275	189
5	321	344	371	305
7	173	62	168	56

These results show that the increases in bacterial density were very similar in both groups of stored samples, from which it would be inferred that the nature of the container, glass, has not been responsible for the bacterial increases observed.

Additional information dealing with the influence of both the nature and the size of the container, on the bacterial behavior in stored samples, was obtained when water was stored in a concrete basin holding approximately

1000 gallons. Under this condition of storage, the rise and fall of the bacterial population, usually observed in stored samples, was again encountered.

Summary

Intensive observations have been made on the bacterial changes occurring in samples of water collected from four sources and held at 10°, 20° and 37° C. The average results obtained from 166 samples are presented. At all three temperatures the bacteria increased to a maximum and then decreased. These changes in bacterial numbers were measured by plate counts at 20° and 37° C., and by Coli-aerogenes group determinations. The maximum numbers of bacteria observed varied in extent with the source of the samples. The time required to reach the maximum, or the rate of increase, varied with the temperature of storage, the rate being most rapid at the higher temperature. At 37° C. the bacteria required about 12 hours to reach the maximum, at 20° C. about 22 hours and at 10° C. about 50 hours. Following the time the maximum was reached, a rapid and a consistent decrease occurred in all samples at the three temperatures. Both the rate and the extent of this decrease varied with the temperature, that is, the decrease was most rapid and most extensive at the higher temperature.

A study has been made of some of the factors which might affect this tendency of the bacteria in water samples to increase and decrease in numbers on storage. The nature of the containing vessel, the size of the sample, the exposure to light, the presence or absence of an air surface as provided by partially filled or completely filled bottles, or a provision for occasional agitation of the sample, apparently did not alter the bacterial changes observed. Centrifuging or filtrating a sample very materially increased the tendency of the bacteria to multiply on storage.

These results apparently suggest that when any change is made in the environment of a portion of water which materially alters conditions, or when the balance existing in the sample of water is disturbed as by centrifuging or by filtration, this disturbance of the balance permits a temporary increase in the numbers of bacteria. And that the more extensive this interference with normal conditions, the greater the increase in bacterial numbers will be and the longer it will be sustained.

Plant Operation

Sludge Digestion at Peoria, Illinois

By Leon S. Kraus

Chemist, Peoria Sanitary District

Treatment Plant.—The sewage treatment plant of the Greater Peoria Sanitary and Sewage Disposal District is of the activated-sludge, separate sludge digestion type (Figure 1). The population served by the plant is about 115,000, but due to the wastes produced by numerous industries the equivalent population within the District's boundaries is conservatively estimated at 1,250,000. The chief sources of these industrial wastes are the Commercial Solvents Corporation plant and two straw-board paper plants.

The wastes from the Commercial Solvents Corporation plant are brought to the treatment works through a separate 12-inch cast iron line. The treatment of the paper wastes will be undertaken in the near future, since experimental work indicates that they can be effectively purified by treatment with activated sludge at a reasonable cost.

Sludge Disposal Equipment.—The treatment plant has four heated digestion tanks of the fixed cover type, each equipped with a Dorr thickening mechanism and scum submerging arm. They are 85 feet in diameter and have a side wall depth of 29 feet (Figure 2). The total digestion capacity is 670,000 cu. ft.

The two storage tanks, each 130 feet in diameter and 33 feet deep, are uncovered and without sludge removal mechanisms. They are steel lined concrete tanks of low cost (approximately $0.125 per cu. ft. of capacity).

The 28 uncovered sludge drying beds have a total area of 280,000 square feet. The dried sludge is removed manually to industrial cars.

Method of Starting Sludge Digestion Tanks.—The development of a proper flora for the digestion of sewage sludge is a difficult problem for the sewage works operator. In many cases the facilities for adequate control are not ready at the time of initiating the plant processes. There is also a fixed idea in the minds of plant operators that once a plant is completed it should handle all of the sewage available. These conditions result in most cases in the overloading of the digestion tanks and are conducive to the production of foam and to long periods of inefficient operation.

In order to establish normal digestion as rapidly as possible the following routine for control and operation is used at Peoria.

A temporary heating installation is provided and the tank is partly filled with water to a depth sufficient to submerge the temporary heating coils. The water is brought to a temperature of 85° to 90° and so maintained after the sludge is introduced.

Daily pH readings are taken from the first day that sludge is added, and when the pH falls to about 6.3 sufficient lime is added to bring the pH to 6.5. The pH of the sludge in the digester is maintained between these values until normal digestion brings the value above 6.5. Sludge

FIG. 1.—View of Primary Settling Tanks, Sludge Digestion Tanks and Open Sludge Storage Tanks. Note Drying Beds in Background and Aeration Tanks in Lower Left.

is circulated from bottom to top as much as possible during this period to prevent the formation of a very alkaline sludge at the bottom of the tank. Since it has been noted that the bottom sludge is in the best condition for seeding the undigested sludge, circulation is maintained until uniform conditions throughout the sludge are established.

After the tank is half full of sludge, volatile acids are determined daily in addition to pH. If the volatile acids are increasing rapidly the load is reduced until they tend to fall off. Then the load is increased by such increments as will not greatly increase the volatile acids. Increases in load are made only when the volatile acids are low (below 700 p. p. m.) and are falling from day to day. If the volatile acids become very high (1500 to 2000 p. p. m.) the tank is rested and no further addition of sludge is made until the acids drop below 1000 p. p. m.

If foaming is encountered the tank is rested and lime and circulation employed.

Single Stage Digestion at 90° F.—The digestion of a mixture of activated sludge and fresh solids involves the handling of dilute sludges. It

was noted that better concentrations of sludge could be obtained by wasting the excess activated sludge to the primary tanks, and that this procedure resulted in a greater volume of gas produced from a unit weight of sludge. This was probably due to a longer digestion period and to a greater percentage of fresh solids in the mixed sludge.

The greatest difficulty in the operation of single stage digestion tanks was the maintenance of a suitable supernatant liquor. Due to the high gas

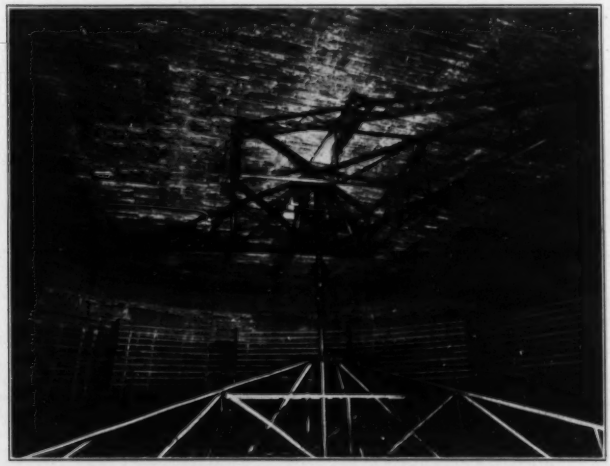


Fig. 2.—Interior of Sludge Digestion Tank, Showing Sludge Removal Mechanism, Scum Submerging Arm and Heating Coils.

production the contents of the tank were stirred to such a degree that homogeneity was produced.

During the period chosen for typical single stage digestion, practically no supernatant liquor was drawn from these tanks. This is evidenced by the reduction in concentration from 5.3 per cent solids in the raw sludge to 3.8 per cent solids in the digested sludge. Good supernatant liquor was obtained, however, from the storage tanks where practically no gasification was noted.

The gas obtained from this digestion was typical of gases from heated digesters.

CO_2	27 to 34 per cent
CH_4	62 to 67 per cent

N_2	4 to 5 per cent
H_2S	40 to 60 grains per 100 cu. ft.

The results during five months of operation are presented in Table I.

TABLE I

SINGLE STAGE DIGESTION

NOVEMBER, 1931, TO MARCH, 1932, INCLUSIVE

Averages on Separate Data for Digesters No. 1 and No. 2

Sludge Added to Digesters	
Solids	5.3 per cent
Volatile Solids	66.5 per cent
pH	6.2
Organic N (dry basis)	3.99 per cent
Total Solids Added Daily	10,300 lb.
Volatile Solids Added Daily	6,700 lb.
Charging Rate (volatile solids per day per 1000 cu. ft.)	40.0 lb.
Temperature	90° F.
Daily Gas Production	55,500 cu. ft.
Digested Sludge	
Solids	3.8 per cent
Volatile Solids	50.1 per cent
pH	7.3
Organic N	2.90
Reduction in Volatile Solids	49.5 per cent
Reduction in Total Solids	34.0 per cent
Gas per Lb. Volatile Solids Added	8.3 cu. ft.

Two Stage Digestion at 90° F.—Due to the difficulty of maintaining a suitable supernatant liquor using single stage digestion, two stage digestion was undertaken with the idea of employing short periods in each tank; the first tank being given over to digestion only, and the second acting to complete the digestion and to allow the separation of supernatant liquor and sludge.

The sludge treated during the period of the above operation was a mixture of activated sludge, fresh solids and digested "beer slop" solids. The data on this operation have been corrected where possible for the digested "beer slop" solids presented. ("Beer slop" is the waste fermented mash from the Commercial Solvents plant.)

Primary tank sludge was pumped into the first stage of digestion and simultaneously sludge was removed from the bottom of the tank at the same rate and for the same period of time to the second stage. Practically no supernatant liquor was wasted from the first tank. Both sludge and supernatant liquor were wasted from the second tank.

The amount of gasification in the first stage was sufficient to make the sludge homogeneous throughout. This great agitation afforded excellent

seeding for the raw sludge added to the tank and at no time was it necessary to circulate the sludge from bottom to top.

The gas production in the first stage of digestion, using a 10.7-day period, was 84.4 per cent of the total gas obtained from both stages. The degree of digestion, as measured by the reduction in volatile solids, was 82.8 per cent of the total digestion.

The supernatant liquor obtained from the second stage was about 35 per cent of the total volume of sludge pumped into the first stage. The character of this liquor was fairly satisfactory as is indicated by the following average analyses:

Suspended Solids	1075 p. p. m.
Volatile Suspended Solids	750 p. p. m.
B. O. D. (5-day)	515 p. p. m.
pH	7.3
Organic N	560 p. p. m.
Free NH_3	480 p. p. m.

TABLE II

TWO STAGE DIGESTION

APRIL, 1932, TO SEPTEMBER, 1932, INCLUSIVE

	First Stage	Second Stage
Sludge Added to Digester		
Solids	3.02 per cent	
Volatile Solids	72.20 per cent	
pH	6.2	
Organic N (dry basis)	4.69 per cent	
Solids Added Daily	27,900 lb.	
Corrected for Digested Beer Slop	20,700 lb.	
Volatile Solids Added Daily	20,000 lb.	
Corrected for Digested Beer Slop	14,300 lb.	
Charging Rate (volatile solids per day per 1000 cu. ft.)		
Corrected for Beer Slop Present	85.7 lb.	
Temperature, ° F.	91	91
Daily Gas Production	94,400 cu. ft.	17,500 cu. ft.
Gas Produced (per cent of total)	84.4 per cent	15.6 per cent
Digestion Period Days	10.7	
Digested Sludge		
Solids	2.47 per cent	3.34 per cent
Volatile Solids	63.56 per cent	61.52 per cent
pH	7.0	7.0
Organic N	4.61	4.42
Reduction in Volatile Solids (corrected for digested beer slop present)	43.4 per cent	53.8 per cent
Gas per Lb. of Volatile Solids Added (corrected for digested beer slop present)	6.6 cu. ft.	7.8 cu. ft.

The gas collected from this digestion was of the same character as that obtained from single stage digestion. No appreciable difference between the gas formed in each stage was noted.

The averages of the data obtained during six months of operation are expressed in Table II.

Digestion of Settleable Beer Slop Solids at 114° F.—As previously stated, the beer slop waste from the Commercial Solvents Corporation plant is brought to the treatment work through a separate line.

Beer slop is the term applied to the waste resulting from the distillation of butyl alcohol, ethyl alcohol and acetone from a fermented mash. A typical analysis of this material is as follows:

Total Solids	1.48 per cent
Volatile Solids	93.36 per cent
Dissolved Solids	0.92 per cent
Volatile Dissolved Solids	88.52 per cent
B. O. D. (5-day)	10,800 p. p. m.
pH	4.4
Organic N	720 p. p. m.
Free NH_3	70 p. p. m.
Temperature	170° F.

The treatment first given this material involved primary settling and sludge digestion. One primary settling tank and one digestion tank were given over to this purpose. The digester received only beer slop solids.

The beer slop was diluted with sewage in order to bring the temperature down to a safe operating condition in the primary settling tank; the effluent from this tank being by-passed to the river, and the settled solids pumped into the digestion tank. The load on the digester was increased very cautiously, the volatile acids in the digested liquor being used as a criterion for proper digestive action.

This treatment was continued until the period in the digestion tank was as short as possible, limited by the pumping capacity of the sludge station.

During this digestion the tank contents were homogeneous throughout, and the digested material was returned to the incoming sewage and given complete treatment. No sludge was wasted from this tank to the storage tanks.

The gas produced by this digestion was of the following type:

CO_2	34.6 per cent
CH_4	60.9 per cent
N_2	4.5 per cent
H_2S	150 grains per 100 cu. ft.

The conditions during the maximum rate of digestion were as shown in Table III.

TABLE III

DIGESTION OF BEER SLOP SOLIDS AT 114° F.

Sludge Added to Digester	
Solids	2.21 per cent
Volatile Solids	94.41 per cent
pH	4.7
Organic N (dry basis)	5.07 per cent
Solids Added Daily	35,500 lb.
Volatile Solids Added Daily	33,480 lb.
Temperature of Digester	114° F.
Charging Rate (volatile solids per day per 1000 cu. ft.)	200 lb.
Digestion Period	6.4 days
Daily Gas Production	306,800 cu. ft.
Digested Liquor	
Solids	0.99 per cent
Volatile Solids	80.84 per cent
pH	6.8
Organic Nitrogen (dry basis)	6.84 per cent
Free Ammonia	320 p. p. m.
B. O. D. (5-day)	1530 p. p. m.
Reduction in Total Solids	55.7 per cent
Gas per Pound of Volatile Solids Added	9.2 cu. ft.

Direct Digestion of Beer Slop.—Because of the odors produced when beer slop waste was settled in these primary settling tanks, direct digestion without settling was attempted. This method has the advantage of decomposing the dissolved as well as the undissolved material.

Since the temperature of the beer slop is about 170° F. the problem of cooling the tanks is of major importance. In order to effect the greatest economy in cooling water, an attempt was made to operate the digester at 150° F. The control at this temperature was most difficult, and the results obtained were unsatisfactory. The odors due to hydrogen sulphide were very objectionable and the volatile acids mounted rapidly. More satisfactory results were obtained by digestion at 134° F.

The data on this operation, expressed in Table IV, are the average results for February, 1933.

Sludge Digestion Data for 1932.—Primary tank sludge (a mixture of activated sludge, fresh solids and digested beer slop solids) was added to two digestion tanks. The presence of the digested beer slop solids is explained by the method used in the treatment of the beer slop waste.

Since the beer slop is a very concentrated waste (15,000 p. p. m. total solids and 93.5 per cent volatile matter) and because of the large amount of dissolved carbohydrates present, it was felt that many difficulties would be encountered in using the activated sludge process for its treatment.

The work of Dr. Buswell and Dr. Boruff pointed to thermophilic digestion of this waste as a most satisfactory method of primary treatment.

TABLE IV

DIRECT DIGESTION OF BEER SLOP AT 134° F.

Slop Added to Tanks	
Total Solids	1.43 per cent
Volatile Solids	93.30 per cent
Dissolved Solids	0.86 per cent
Volatile Dissolved Solids	88.76 per cent
B. O. D. (5-day)	11,500 p. p. m.
pH	4.4
Organic N	720 p. p. m.
Free NH_3	70 p. p. m.
Temperature	165° F.
Solids Added per Day	16,000 lb.
Volatile Solids Added per Day	14,900 lb.
Charging Rate (volatile solids per day per 1000 cu. ft. tank volume)	89.3 lb.
Temperature of Digester	134° F.
Digestion Period	9.6 days
Daily Gas Production	198,800 cu. ft.
Digested Liquor	
Total Solids	0.44 per cent
Volatile Solids	80.81 per cent
Dissolved Solids	0.22 per cent
Volatile Dissolved Solids	71.70 per cent
B. O. D. (5-day)	2500 p. p. m.
pH	7.1
Organic N	280 p. p. m.
Free NH_3	450 p. p. m.
Gas Analysis	
CO_2	38.2 per cent
CH_4	58.2 per cent
N_2	3.6 per cent
Gas per Pound of Volatile Solids Added	13.3 cu. ft.
Reduction in Total Solids	69.1 per cent
Reduction in B. O. D.	78.2 per cent

It was therefore decided to treat the beer slop first by digestion and subsequently by settling and activated sludge.

Due to the rapid rate of gasification obtained in this digestion, the digested beer slop was stirred so violently that no sludge could be wasted to the storage tanks. The digesters were allowed to overflow while being charged, the digested liquor mixing with the primary tank influent, and complete treatment afforded it. Thus the digested beer slop solids settled in the primary tanks with the excess activated sludge and fresh solids, and this material was added to two of the digestion tanks for stabilization and ultimate disposition.

The sludge from the primary tanks, which averaged 3.54 per cent solids and 71.72 per cent volatile matter, presented no appreciable pumping difficulties. With the exception of a rather heavy scum blanket encountered during the initial period of digester operation, scum troubles were entirely absent. The scum draw-off lines were not used during the entire year.

Due to splashing and the consequent entrainment of sludge in the gas, it was found necessary to raise the vertical gas withdrawal pipes on the collecting domes from $2^1/_2$ feet to 8 feet above the sludge level. This was accomplished by raising the 4-inch gas withdrawal line and housing it in an 8-inch sheet metal pipe closed at the top (Figure 3). This procedure entirely obviated the difficulty.

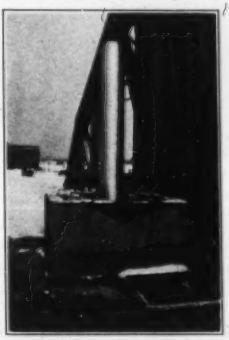


FIG. 3.—View of Improved Gas Dome. The Maximum Water Seal Available Has Been Increased from 11 Inches to 35 Inches. The Gas Withdrawal Line Has Been Raised from $2^1/_2$ Feet to 8 Feet Above the Sludge Level.

The digested sludge which was pumped to the storage tanks contained an average of 3.17 per cent solids and 60.68 per cent volatile matter. In the storage tanks some additional concentration and digestion took place; the sludge to the drying beds having averaged 4.08 per cent solids and 56.13 per cent volatile matter.

The data on gas production are analyzed in Table V.

TABLE V

DAILY AVERAGES OF GAS PRODUCTION BY MONTHS FOR 1933

Source	Sewage Sludge, Cu. Ft.	Beer Slop, Cu. Ft.	Total, Cu. Ft.
January	105,100	26,200	131,300
February	109,300	59,800	169,100
March	110,700	110,400	221,100
April	120,600	167,600	288,200
May	105,600	247,300	352,900
June	111,400	307,400	418,800
July	112,100	291,400	403,500
August	111,400	278,600	390,000
September	105,300	126,100	231,400
October	96,800	199,400	296,200
November	96,100	167,400	263,500
December	100,000	107,800	207,800
Average	107,000	174,100	281,100

Typical analyses of the gases are given in Table VI.

TABLE VI

TYPICAL GAS ANALYSES

Source of Gas	Sewage Sludge at 90° F.	Beer Slop Solids at 115° F.	Beer Slop at 134° F.
Carbon Dioxide	27.8 per cent	34.6 per cent	38.2 per cent
Methane	67.5 per cent	60.9 per cent	58.2 per cent
Nitrogen	4.7 per cent	4.5 per cent	3.6 per cent
Hydrogen Sulphide (grains per 100 cu. ft.)	65	150	...
Gross B. t. u. per cu. ft.	670	610	580

Based on tributary human population the average gas production for the year was 3.12 cu. ft. per capita per day. The maximum for one month was 4.64 cu. ft. per capita per day. The largest amount of gas produced during one day to the date of this writing was 594,300 cu. ft., or 6.6 cu. ft. per capita of tributary population.

Based on population equivalent data, using 0.15 pound of volatile solids

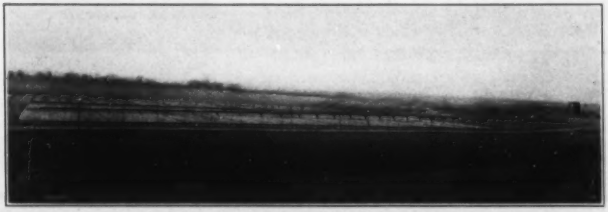


FIG. 4.—Sludge Drying Beds at Peoria.

per capita per day, the average gas production was 1.4 cu. ft. per capita per day. This figure is resolved into two parts: for sewage sludge 1.2 cu. ft. per capita per day and for beer slop 1.6 cu. ft. per capita per day.

Sludge Drying and Disposal.—Nine removals of sludge from the drying beds (Figure 4) during 1932 resulted in a yield of 18.5 pounds of dry solids per square foot per year. This low figure is primarily due to the low concentration of solids in the sludge charged to the beds (4.08 per cent). The amount of water removed from the sludge was 421 pounds per square foot per year.

The average analysis of sludge removed from the drying beds follows:

	Per Cent
Moisture	53.2
Volatile Matter	53.9
Organic Nitrogen	3.54
P_2O_5	2.41

Practically all of the sludge removed from the beds to date has been used as fertilizer by enthusiastic farmers.

COST OF SLUDGE DISPOSAL FOR 1932

Sludge Treated		
Sewage Solids	6,450,000 lb.	
Beer Slop Solids	6,430,000 lb.	
Total	12,880,000 lb.	6,440 tons
Operating Cost		
Operators and Maintenance Man	$6,900	
Superintendence and Laboratory	1,900	
Power	900	
Maintenance	500	
Cost of Sludge Removal	4,300	
Cost of Resanding Beds	1,200	
Total		$15,700
Capital Cost		
Sludge Digestion Tanks	$230,813	
Pumping Station	64,057	
Storage Tanks	109,984	
Storage Pumping Station	19,850	
Sludge Beds	112,738	
Total		$537,442
Fixed Charges, 7.8 per cent of $537,442 =		41,900
Total Cost of Treatment		
Operation Cost	$15,700	
Fixed Charges	41,900	
		$ 57,600
Cost per Ton of Sludge Treated		$8.95

Present Thoughts on Sludge Digestion

In the past two years our experiences at Peoria have led us to the following conclusions:

That primary tank sludge concentrations of from 3 per cent to 5 per cent are attainable where activated sludge and fresh solids are of the order of a 1:1 ratio on the dry basis.

That the above concentrations are controlled to a large extent by the per cent volatile matter in the sludge.

That sludge after digestion and storage does not increase appreciably (1 per cent) in concentration over its initial concentration as primary tank sludge.

That digestion at 90° F. with a 10-day period will result in a 40 per cent reduction of volatile solids.

That digestion tanks should be operated at such a charging rate as will result in sufficient agitation by gasification to make the entire tank contents homogeneous. This results in excellent seeding for the undigested solids and enables tanks to be operated at high rates.

That separation of supernatant liquor and sludge can best be obtained in secondary digestion tanks.

That, since the amount of gas produced in secondary tanks is small, these tanks may be uncovered.

That thermophilic digestion can be maintained at temperatures between 115° F. and 135° F.

That the percentages of both carbon dioxide and hydrogen-sulphide increase with the temperature of digestion, within reasonable limits.

That supernatant draw-off manholes should be designed to minimize the corrosive action of the hydrogen sulphide in the digested sludge or liquor drawn from a tank.

That in all sludge digestion tanks the development and maintenance of a proper flora is of utmost importance.

Acknowledgment

The author wishes to express his appreciation to the Trustees of the Greater Peoria Sanitary and Sewage Disposal District, Messrs. F. Roy Miller, Frederick V. Arber and Wm. C. Leitner, to its engineer, Mr. J. R. Longley and to Mr. A. T. Jensen, plant superintendent, for the excellent help and coöperation that make this paper possible.

Notes on the Operation of Sewage Treatment Plants*

BY LEROY W. VAN KLEECK

Senior Sanitary Engineer, Connecticut State Department of Health

This paper deals with only the common methods of sewage treatment in New England, omitting special processes and sewage chlorination. The topics include: plain settling, separate sludge digestion, Imhoff tanks, septic tanks, sand filters and sludge drying. The following observations and comments are based on the writer's experience in visiting sewage treatment plants in Connecticut as a representative of the State Department of Health.

Plain Settling

Connecticut has twelve plain-settling tanks of five varieties. Mechanical screens and grit chambers ahead of the tanks are usually desirable. Rags clog sludge pipes, valves and pumps; grit forms shoals in the tanks. These shoals interfere with sludge removal. At several Connecticut plants treating storm sewage or connected with old separate sewers, it has been necessary to empty the tanks once or twice a year for inspection and cleaning, although mechanical equipment for rag and grit removal is employed. At such times a stand-by unit is essential in maintaining a good plant effluent, while the tanks are cleaned in rotation. Tight inlet and outlet gates should be provided for each tank.

Primary sludge is usually removed from plain-settling tanks at least daily. There are exceptions and each plant is a special study. Sludge soundings, the percentage of solids in the primary sludge, septic action in the tanks and the character of the effluent are all indicators for sludge removal. When water streaks appear, the sludge pumping should generally be stopped. The pumped sludge at Connecticut plants varies from 2 to 10 per cent solids.

Sludge removal from shallow settling tanks through gravity pipes has proved difficult. Likewise centrifugal pumps are sometimes unsatisfactory, as they may suck through the sludge blanket, leaving much of the sludge in the tank. Other disadvantages experienced with centrifugal pumps have been that excess water pumped with the sludge has resulted in chilling digestion tanks and increasing the volume of overflow liquor. Non-clogging types of centrifugal pumps under some circumstances, however, may be satisfactory. Slow-acting plunger or diaphragm force pumps have been found very suitable for sludge pumping.

* *Presented at the Spring Meeting of the New England Sewage Works Association, Woonsocket, Rhode Island, May 1, 1933, to open a Round Table Discussion on "Operating Difficulties with Sewage Treatment Plants."*

In pumping sludge an advantage is gained by using bottom draw-offs, preferably with side suction. Riser pipes, suspended above the bottom of the sludge sump, leave some sludge in the hopper after pumping. This sludge soon becomes septic—rises—forms scum. Scum means unsightly tanks and skimming.

Scraper runs vary considerably, depending on the volume of sludge and type of tank, the scrapers at one plant being operated 24 hours daily; at others less than 1 hour daily. The scrapers should operate sufficiently to move all the sludge to the point of removal, and to avoid overloading of the mechanism.

When the scrapers operate, especially at the start of a run, a small amount of sludge will often rise to the surface of the tank. Although scum boards are usually built to retain this material, some will escape. It is occasionally possible and desirable to remove a unit from service during the scraping and pumping of sludge.

Scum removal facilities are necessary since certain materials, particularly grease and oil, float. A few tanks were installed in Connecticut without scum boards or with boards that were too shallow. At New Haven mechanical skimmers sweep the scum to small reservoirs built in the sides of each tank, and from these reservoirs the scum flows to a special skimmings tank. At Danbury a section of the baffling is removable, and the scum is floated to a special sand bed for drying. A moderate wind will concentrate scum in one corner of the tank where it can be skimmed by hand. Results at one plant show that fine screening prior to tank treatment does not remove all floating material, and scum baffles are still needed for the tanks. Unless settling tanks are skimmed periodically, they will produce odors and present an unsightly appearance.

Common faults in the design of these tanks are poor flow distribution and short-circuiting of the sewage through the settling units. Two or more tanks frequently receive unequal flows, the result of poor inlet channel design. Several types of channel deflectors have been tried in Connecticut with varying success. Dye studies at a number of plants have revealed short-circuiting of the sewage to the tank outlet in about 20 minutes. Although dye tends to spread over the surface of tanks, these studies certainly have significance.

One type of plain-settling tank that has particularly appealed to me is the circular radial outward-flow tank with peripheral weirs and spiral scrapers. With this type of tank the scraper runs are short, the primary sludge heavy and the overflow liquor correspondingly small in quantity. A minimum of short-circuiting appears probable, and the effluent is of good quality. To level the weir sections, adjustable slots are provided for raising or lowering the weir plates as desired.

In general, plain-settling tanks are good investments when skilfully

operated. Careless operation is costly. Mechanical repairs have been minor at most Connecticut plants, the oldest of which has been in operation since 1929.

Separate Sludge Digestion

Control is the distinguishing feature of separate sludge-digestion tanks. Heated tanks should be used more frequently in New England. If unheated tanks are used, long storage is essential. Large capacity tanks increase the cost, which could better be spent in gas-burning equipment. Gas-heated tanks not only maintain good digestion throughout the year, but control odors, frequently provide fuel for heating at the sewage plant and prevent spring foaming troubles. Unheated tanks may require continuous liming to control scum and promote digestion; they give off some odor; and the final product is not always well digested.

The sludge drawn from heated tanks in Connecticut generally runs more than 50 per cent ash (dry basis), has a hydrogen-ion concentration of between 6.8 and 7.1 and a solids content of 7 to 18 per cent. Tank temperatures of 80° to 85° F. are common. A temperature from 85° to 95° F. hastens digestion, but limited observations at one plant show excessive scum formation with such high temperatures.

Because repairs are sometimes necessary, and to provide flexibility in operation, two small digestion tanks at a plant are preferable to a single large one.

In starting the average sludge-digestion tank the following procedure has been tried at several Connecticut plants with good results: First fill the tank with fresh sewage before adding any sludge; then add fresh primary sludge mixed with milk of lime as often as necessary to keep the settling tanks clean; third, circulate the bottom sludge to the top several hours daily and lastly, stop liming at a pH of 7.5 or slightly under. The pH should rise very slowly, otherwise too much lime is being used. Circulation of sludge has usually been discontinued with the liming. Ripe sludge, when available, is excellent for seeding, and sometimes precludes the need for liming.

Many methods of adding lime have been tried at Connecticut plants. Large quantities added dry tend to lump or cake in the bottom of the tank. This may mean emptying the unit. To those operators who have never had this experience let me say that it is most unpleasant. Milk of lime, prepared from a lime slurry of water or sewage with lime and added to the primary sludge, has mixed well, avoided lime pockets that inhibit digestion and is an economical, convenient procedure. The amount of dry lime used has varied from 25 to over 200 pounds daily. In some unheated tanks 25 or 50 pounds is added weekly during most of the year.

The scum problem must be faced at many plants, especially if fur, hair, skins or fabric wastes reach the sewers. Scum can be broken up, floated

off or removed with pitchforks from manholes—allowing it to accumulate may lead to trouble. Several supernatant liquor draw-offs are a great convenience. At Old Greenwich such pipes are provided on 18-inch centers throughout the depth of the tank. At New Canaan, where activated sludge is digested with primary sludge, the clear-liquor layer in the digestion tanks varies considerably, and the superintendent has devised an adjustable draw-off siphon for decanting.

We have drawn no conclusions concerning the benefits of stirring mechanism for these tanks, although an advantage may be indicated for plants treating industrial wastes. Such mechanism requires attention, and breakdowns are serious, as they mean emptying the tank for repairs. Our experience indicates that some manufacturers may be building this equipment too light for the loads incurred.

The primary-sludge inlet and overflow-liquor outlet should be located at opposite ends of the tank to avoid short-circuiting. Short-circuiting occurs at one plant where the point of sludge inlet is located one-quarter of the tank's circumference from the overflow.

A bottom outlet for sludge circulation and removal appears preferable to a side outlet. With stirring mechanism a bottom outlet, centrally located, is particularly important, since the greatest sludge concentration occurs there. A change from side to bottom outlet was made at one Connecticut plant.

Is overflow liquor a major problem with these tanks? The answer depends on the rate of sewage flow, and the facilities provided. When returned to the raw sewage, the rate of liquor return and the point of return are important. The volume of liquor is generally 0.1 to 0.4 per cent of the daily raw sewage flow. At one plant the liquor is returned slowly for settling in an old septic tank, the effluent from which mixes with the raw sewage. At several plants the liquor is successfully returned unsettled to the raw sewage at the rate of primary sludge pumping. Good mixing with the sewage is essential. Filtering this liquor through sand will result in a high removal of suspended solids. When it is desired to withdraw overflow liquor at a slower rate than the incoming sludge, a floating cover allows flexible operation.

The high chlorine demand of this overflow liquor must be considered when the final plant effluent is chlorinated. At Norwalk the chlorine demand of the plant effluent doubles when overflow liquor is wasted to the chlorine contact chamber. During the wasting period the ratio of liquor to sewage effluent is about 1:17.

Imhoff Tanks

In the State of Connecticut there are fourteen Imhoff tank sewage treatment plants, of which eight are municipally operated, three state

operated and three privately operated. The following remarks indicate how certain operating difficulties were overcome:

Grit clogs the valves and pipes of these tanks and should be excluded whenever possible. In the absence of grit chambers, shoveling the material at regular intervals from the inlet channel to the tanks is very helpful and practical, thereby preventing much of the grit from collecting in the end hoppers. The presence of grit in Connecticut tanks has resulted in several cases where the tanks had to be emptied and the grit removed with buckets.

Coarse bar screens of 1- to 2-inch clear openings are very desirable. If the screenings are very voluminous, a mechanical screen is a good investment. When screens are not provided, improved operation has been obtained by removing rags from the gas vents with a tomato fork, since rags left in the vents digest slowly and tend to mat the scum.

Hand-skimming the sedimentation compartments of large quantities of oil and grease is laborious. Skimmings thrown in gas vents digest slowly and interfere with proper operation. One way to avoid hand-skimming is by the use of scum draw-off pipes located in the flowing-through chambers. When the tank outlets are closed, the liquid level rises slightly, and the scum is floated into these pipes, and thence on to a special drying bed or the regular sludge beds.

When grease is very abundant there is probably much merit in a special chamber for collection, as for example in the Imhoff aerating system. Discharge of oil and gasoline into sewers should be prohibited by local ordinance. The enforcement of such ordinances has been difficult in some communities.

Deflectors in the inlet channel to Imhoff tanks have equalized the flow to the individual units. These deflectors should be adjustable to allow for flow variations. Reversing the flow in tanks is usually possible and often desirable to equalize the sludge level. Dye studies show, as with plain-settling tanks, that inlet and outlet baffles aid in giving a uniform cross-sectional flow and reduce somewhat short-circuiting of the sewage. Many of these tanks short-circuit sewage to the outlet in less than 20 minutes. Observations at Watertown indicate improved sedimentation by using series operation of the tanks, but parallel operation is usually recommended. The use of wide effluent weirs, rather than submerged or narrow outlets, gives improved effluents. Many of the older tanks in Connecticut have faulty effluent weirs.

Frequent drawings of sludge in small quantities are giving better results than infrequent drawings of large amounts. Sludge valves require careful manipulation to avoid pulling holes through the sludge, especially in shallow tanks. When tank hoppers are few and no dividing walls separate the sludge compartment, the sludge is more uniform, and is drawn with greater ease. Some of the Imhoff tank plants in Connecticut are

overloaded, and winter sludge drawing is necessary. This sludge is removed frozen from the drying beds without difficulty.

Regular sludge measurements are important in Imhoff tank operation. A No. 4 pitcher pump with $1^1/_2$ inch steam-pressure hose has been very satisfactory for these soundings if the apparatus is properly constructed and carefully used.

Another sludge-sounding method involves the use of a bottle or metal can with stopper and spring. The apparatus is lowered in the tank with a link-chain, the sludge level assumed and the stopper pulled by means of a wire—the sludge level is quickly found.

Another device made by T. McMahon of Stamford consists of a toilet ball-float weighted to sink slowly in sewage. When the sludge-level is reached, the bulb comes to rest. A clever improvisation, used by the superintendent at Norwalk, utilized a pint mason jar containing water.

An electric sludge-sounder invented by Geer and Reinartz of South Manchester is of interest. The apparatus consists of a box containing the necessary equipment, on top of which is a galvanometer for recording electrical deflections. An electrically charged wire is lowered through the tank, only the terminal of which is exposed, and when sludge is encountered a deflection is recorded on the galvanometer. The device was successfully demonstrated at several plants in Connecticut. It is unfortunate that this device, or some adaptation of the electric eye, has not been commercially developed.

Gas bubbling in sedimentation chambers is usually the result of a high sludge level or slots and aprons that need squeegeeing. Sometimes if the sludge is working violently, gasification will occur in these chambers. This is especially true of shallow tanks. Imhoff tanks also seem subject to seasonal overturns such as occur in natural lakes. Such circulation will cause some liberation of gas. Inspection manholes through the aprons are undesirable, as they are easily dislodged by gas. The writer prefers the overlapping apron to the triangular beam, as the former is easier to clean and clogs less. The triangular beam is a clothes-line for rags and sewer growths. Every spring the beam-slots at one Connecticut plant are virtually closed by long strands of *sphaerotilus natans*, which are washed to the plant from the sewers. Squeegees are better for cleaning beam slots than a chain. The cleaning apparatus should not be too heavy.

Foaming is a major operating difficulty, sometimes caused by a lack of appreciation of the delicate balance in Imhoff tanks. The common methods of correcting foaming have been tried in Connecticut with the usual varying results. Certain operating factors have been observed:

Excessive hosing aggravates foaming, interferes with sedimentation and increases the chlorine demand of the tank effluent. It is preferable to shut down a tank being hosed or squeegeed.

Deep tanks with adequate storage have foamed less than shallow tanks with limited storage. In either case drawing sludge, resting or both have been very beneficial in correcting foaming.

Maintaining alkaline conditions in Imhoff tanks sometimes prevents foaming. Small periodic additions of milk of lime to the gas vents or sludge compartments have accomplished more in this direction than large quantities dumped at one time. At Wallingford where there is no scum in the gas vents and no foaming, fifty pounds of lime are added weekly to the vents in each tank.

At six Imhoff plants, where there is virtually no scum in the vents during the greater portion of the year, the vents receive regular attention, although other factors than agitation, liming and removal of scum may be involved in reducing the scum problem. At some plants outside Connecticut very little gas vent work is done with no apparent decrease in operating efficiency.

At one Connecticut plant deciduous trees near the tanks shed leaves into the gas vents. These leaves interfered with digestion, so the vents were screened.

The experience of the Connecticut State Department of Health clearly indicates that Imhoff tanks of proper capacity and depth will function satisfactorily under good operation.

The general appearance of these plants is important. Appearance is improved by landscaping, providing storage for tools and equipment, using cans for screenings, skimming the tanks regularly and using the water hose liberally. Adequate neat records reflect a business-like management and aid in the operation. Cleanliness is good insurance against odors. Prechlorination has sweetened septic sewage at several plants and reduced odors. Drawing sludge under favorable weather conditions or using chemical conditioners will reduce odors. No sewage plant is a perfume factory, but by intelligent operation odors from Imhoff tanks can usually be kept below the nuisance stage.

Septic Tanks

Septic tanks properly built have given good results for small plants. Burying these tanks under several feet of earth cover and providing only one or two manholes for inspection are not conducive to good operation. Septic tanks need cleaning at periodic intervals, and at such times the inside of the tanks must be accessible. Large plank hatchways or steel sidewalk doors have been successfully used as covers in Connecticut. For the larger tanks, adjustable wide weirs with inlet and outlet baffles are preferable to submerged inlet and outlet pipes.

Many old septic tanks in Connecticut were designed for long detention of sewage, resulting in septic effluents difficult to oxidize with sand filters. When two parallel units are built, only one unit should be used for low flows. In some cases tank capacities have been temporarily reduced by using plank division walls. With reasonable detention in septic tanks and periodic cleaning, say twice a year, the advantages of plain-settling tanks are partially realized.

The principal advantage of septic tanks is the small amount of operating attention they require. The inherent disadvantage is the difficulty of digesting the sludge and scum in contact with fresh settling sewage without disturbing the sedimentation process.

One way of obviating this disadvantage is by building from two to five septic tank units in parallel, rotating the tanks in operation. After a tank is used for a period of time—say three to four months—it is shut off and the contents allowed to digest. Griffin in Greenwich has secured good results by pumping ripe sludge from a digesting tank into a tank just shut off. At the same time, and occasionally during the digeston period, the scum in the new tank is broken up. Circulation of sludge is beneficial when possible. By this process of seeding, a fairly satisfactory sludge is produced, which is unusual for this type of tank.

In cleaning septic tanks in Connecticut, it is our experience that the best results are obtained by completely emptying the tanks whenever possible. Sometimes this means using a portable pump. Following a thorough cleaning, excellent removal of solids and B. O. D. is effected for several months under average conditions. We do not believe in seeding tanks in use, or leaving any seeding material when drawing sludge, as is done in the case of Imhoff or separate sludge-digestion tanks, because the ensuing digestion interferes with sedimentation.

In my opinion, riser sludge pipes in septic tanks are ineffective, as some sludge will always remain in the tank and scum cannot be removed through them. In many septic tanks all the solids rise as scum. In such cases a scum draw-off is a convenience. The scum can either be floated by the sewage into wooden troughs and thence to the sludge beds, or it can be floated into drop manholes and washed on to the beds through sludge pipes. At small septic-tank plants without sludge beds, the tanks must be pumped and the solid material removed in tight wagons or drums. When cleaning tanks at some plants the clear liquor between the scum and sludge has been returned to the inlet of the tank in use without detrimental results. This practice relieves the sludge beds of much liquor, or saves labor when trucking the material.

Sand Filters

During high flow or poor weather conditions, increased drainage is obtained through sand filters using a small wheel-harrow or loosening the hard crust on top of the sand. Little deterioration in the quality of the effluent has been observed, although the results are still under study. Sand filters are not corn fields to be cultivated, and the harrow should loosen only the topmost sand.

The writer sees no need in furrowing for winter operation, as sub-surface clogging is likely. If protection against ice is considered necessary, rake

the sand into small piles instead of disturbing it to great depths. Careful dosing, harrowing, cleaning the beds when possible and maintaining a good tank effluent will usually prevent flooding all but overloaded or very poor beds. Reasonable rates of filter loading, adequate underdrain systems and quality of filter sand cannot be over-emphasized in design.

Siphon chambers and the dosing apparatus need attention. Weekly cleaning of siphon chambers is common practice at Connecticut plants. The clean-out pipe for the chamber should be on the bottom and preferably discharge to one of the sludge beds to avoid fouling the sand filters. Once or twice a year the siphon dosing apparatus should be cleaned and overhauled.

Some filters are built too large for efficient dosing, cleaning or leveling. Small units offer flexibility in operation.

Weeds are sometimes an operating difficulty, particularly with old filters or those containing unwashed sand. At Plainfield a steel blade suspended between small wheels is rolled over the sand-surface, loosening the weeds very effectively. Weed burners are also used. A good quality grass seed for embankments reduces weed growth on the filters and improves their appearance. Chemicals have not been used in Connecticut for weed destruction.

Sludge Drying

Sludge drying is an important matter at many plants, especially when drying bed area is limited and careful odor control is required.

With regard to open or closed beds, many plants could profit with a few of each. When glass-enclosed sludge beds are built, remember they are intended as drying beds, not greenhouses, and provide proper facilities for ventilation and operation. It is not uncommon to find these beds with high concrete side walls, which exclude the sun, and with ventilators of improper design. Ridge-and-valley enclosures are not advisable in New England, as snowloads may break the glass panes in the valleys. At one Connecticut plant one hundred panes were broken in a recent storm.

Covered beds should be closed, or nearly so, the first day sludge is drawn, at night or whenever weather conditions are poor for drying. At night when the air is heavier and most people have leisure, odors are likely to be noticed. If the sludge is inodorous or the drying beds are removed from dwellings, precautions are not so important.

Sufficient depth of sand in sludge beds is needed for removal of suspended solids and color, and to offset sand losses with sludge removal. A sand depth less than six inches is not recommended; over one foot is better. One-and-a-half feet of good quality sand produces a clear effluent from most sludge liquors. The drying bed underdrains should discharge to the chlorine contact chamber, when provided, for disinfection of the bed

effluent. When tides affect the beds, gate valves manually closed at high tide will keep salt water from flooding the underdrains or beds. Automatic flap valves are not always tight.

In the winter, sludge in Connecticut is removed frozen from open sludge beds. The removal is not difficult and less sand is lost than in summer operation.

The drying period may be shortened during rainy seasons by spading channels in partially dried sludge to conduct the rain water to the sand instead of allowing it to pool on the sludge.

Chemical drying and control of sludge odor have been tried in Connecticut at West Haven, Stratford, Norwalk and Greenwich, using chloride of lime in doses varying from 1 to 15 pounds per thousand gallons of sludge. The chemical has been spread dry on the sand, thrown over the surface of the applied sludge or added as a solution to the sludge during the dosing period. Plugging of the sand may occur if large doses are used or if the practice is continued for long periods of time, especially with dry applications. Odors seem definitely decreased, and one plant reports that the drying period is halved. Alum was tried at one plant, but no conclusions were drawn.

Wetting the sand on sludge beds prior to dosing sludge has been tried at Greenwich. Quick drainage of the sludge liquor by release of bound air is reported.

Sludge drying is a process requiring care from the time of dosing to the removal of the dried cake.

Conclusion

Regardless of the method of treatment or the means of disposal, conscientious, intelligent operation is essential. A poor plant, well operated, may easily surpass the good plant, poorly operated. Adequate records, measurement of flow and laboratory facilities all have their place, but most important is the human factor.

Symposium—The Operation of Small Sewerage Systems and Treatment Plants*

LED BY WILLIAM A. RYAN

Consulting Chemist, Rochester

The most important factor in sewage disposal is the upkeep of the sewage treatment plant. The best way to have a well-kept plant is to employ a well-trained plant operator. The operator must have mechanical and electrical experience and a little chemical knowledge to be able to cope with the various problems which present themselves in the course of the day's work.

In addition to the above, the operator must have a certain amount of interest and pride in his work. The best way to inspire interest in the work is to pay the operator a sufficient wage to insure a decent living for himself and family. The operator will have a greater incentive to impress the public and will perform his duties with greater enthusiasm if the plant is under the watchful eye of the public.

In many villages the plant is located near a stream or river on the outskirts of the town and the location is unknown to many of the inhabitants until stray odors may bring it to their attention.

All the troubles in operation should not be charged to the operator as in many cases the design of the plant is faulty or the plant has become antiquated and should be replaced by a plant of modern design.

Progress in methods of treatment, the invention of modern machinery and present knowledge of the functions of the various units of the plant, make it possible to locate a treatment plant within the village limit. The plant should be constructed along lines of architectural beauty and the grounds should be well landscaped. In this way, the plant will be attractive, well operated and the taxpayer will see the importance of protecting a big investment.

In locating a plant nearer the center of the village, the operator will have access to an adequate water supply and will not find it so difficult to reach the plant in times of inclement weather.

Today people are economy minded. It is necessary for operators and superintendents to impress upon the village board that sewage treatment is important and necessary to the health of the people. You have the opportunity, at this time, to rise above the problems of economy and unfair criticism.

The successful operation of a sewage treatment plant is an important business. The operator who joins the sewage works association, attends

* *Presented at the Spring Meeting of the New York State Sewage Works Association, Rochester, N. Y., June 9–10, 1933.*

the conventions, reads the journals devoted to problems of the treatment of water and sewage and attends a school for operators, is more successful than the operator who takes no advantage of his opportunities.

There are two main objectives in sewage treatment. One relates to the sewage entering and treated within the plant, and the other to the effluent discharged into a stream or other body of water. The second objective is mainly dependent upon the first. If the sewage is properly treated within the plant there will be no infringement of riparian rights upon its discharge into the stream.

In accordance with the purpose of this symposium, I will briefly make a few suggestions which may help the operator of the small sewage plant.

Every man must take his work seriously. Careful and continuous attention must be paid to details. The operator should know the purpose of each unit of the plant. If the plant is new, the designing engineer will furnish this information; if old, and the operator has replaced a former employee, it will be necessary to obtain this information from the engineers of the Sanitation Division of the State Health Department or from a consulting engineer.

The designs of various plants differ to such an extent that it is difficult to lay down any rules of operation except of a general nature.

Rough racks should be cleaned daily, grease and organic matter which collect on the inner walls of the Imhoff or septic tanks should be scraped down at frequent intervals. Rough rack screenings and scum from the tanks or gas slots should be buried or placed on land and plowed under or incinerated.

The sprinkler nozzles should be cleaned at the first sign of clogging and the top stones turned over at least twice a year.

The secondary tank may be shallow or deep. If shallow, more frequent removal of sludge will be necessary to avoid a carry-over of the sludge with the final effluent. Use plenty of water to wash down the tank walls, the dosing chamber and other parts of the plant where septic solids are apt to lodge.

Forms are provided by the State Health Department which make it possible to keep a record of the plant's performance. If these forms are carefully and correctly filled out each day and forwarded to Albany at the end of each month it enables the State Sanitary Engineer to be of greater assistance to the operator. Carefully kept records will result in improved plant operation.

The general appearance of the plant and grounds reflects the general interest of the operator. Weeds and grass should be cut at regular intervals; shrubs should be trimmed back once a year and leaves raked and burned.

Every operator should ask himself, "Am I proud to show the plant to visitors?"

The average visitor is not familiar with the details of operation but judges the performance of the plant by its general appearance and the odor about the plant.

Sufficient tools should be at hand to enable the operator to perform the various duties with ease and efficiency. When the tools are not in use they should be stored in a dry place, or in a suitable box provided for this purpose.

Many operators have other duties to perform besides the care of the sewage plant. This makes it all the more necessary to plan the day's work so as not to neglect the treatment plant. It is well, whenever possible, to have an assistant with you when working in any underground compartment. Remember sewer gas is not only explosive but suffocating as well.

In conclusion, I will briefly summarize as follows:

A sewage treatment plant must receive daily attention to make it operate successfully. The operator must know the plant and plan his work so as not to neglect any duty.

The records of the plant's operation should be kept daily.

Measure and record the depth of sludge in the sludge compartment once a week.

Never withdraw all the ripened sludge.

Never fill the sludge bed to a depth of more than one foot.

Use the hose freely for breaking up scum in the gas slot and cleaning the walks, sidewalls of the tank, slots and rough racks.

Do not allow the filter beds to pool or stand flooded for any length of time. This upsets the biological action and drowns all life other than bacteria in the beds.

Remember the A B C of sewage treatment:

Attention to details.

Businesslike system in operation.

Cleanliness.

Take care of your job and your job will take care of you.

Discussion

Covered Sludge Drying Beds and Sludge Drying at Town of Tonawanda, Plant No. 2

BY ALFRED W. EVANS

Superintendent, Department of Public Works, Town of Tonawanda, New York

The original disposal plant on the Two Mile Creek Road, Town of Tonawanda, was built in 1922 and consisted of two Imhoff tanks 35 ft. in diameter by 32 ft. deep, each with a capacity for 5000 population; and an open sludge bed 175 ft. long by 44 ft. wide with a wooden partition running

through the center. It was of the hill and valley type with 3-in. V-tile open joints connecting with the 6-in. V-tile main drain, which had cement joints.

The filtering material of the sludge bed was 10 in. of graded gravel over which 2 in. of sand was spread. We pump 8 in. of wet sludge into the beds for drying. Weather conditions are of great importance with open sludge beds, for if rain falls within 24 hours after running sludge the time for drying is lengthened and odors arise. It was frequently a month before we could remove the sludge from the beds after a heavy rainfall. We had from 4 to 5 dryings a year with the open beds as compared with 10 dryings a year with the closed beds. Most of the dried sludge was used for filling in low spots around the plant.

In 1927 it became necessary to enlarge the plant, due to the increased population. A screen and distribution chamber was built in the line of the 48-in. sewer. The screen is made of bars $2^1/_4$ in. $\times$ $^1/_4$ in. set 1-in. centers on a 45° angle for the full width of the distribution chamber, which is 36 ft. long, 10 ft. wide and 5 ft. 6 in. deep at its lowest point which is the center. Two additional Imhoff tanks and a glass-covered sludge drying bed were also constructed.

Four 12-in. cast iron pipes lead from this point to the chamber in each Imhoff tank. The flow in the Imhoff tanks is half around the tank to the effluent weirs, over which the sewage flows into a trough connected with a 12-in. V-tile pipe that leads to a collecting header and takes the sewage to the chlorinator house. There it is treated with chlorine from a Wallace and Tiernan solution feed machine. The sewage flow is also measured at this point by a recording weir and a Cochrane recorder. The water is also metered and we have the necessary laboratory equipment to make the tests which the State Department of Health requires.

The chlorine is purchased in containers of 2000 lb. capacity. We use from 200 to 250 lb. every 24 hours and from 10,000 to 12,000 gallons of water in the solution-feed machine. The capacity of the plant after the enlargement was made was 22,000 population, and about 18,000 are being cared for at the present time.

The plant was somewhat handicapped due to the fact that during rain storms the tanks were flooded by surface water running into sanitary manholes, which made it very hard to keep the Imhoff tanks clean, and also resulted in additional work for the operator at the plant.

In March, 1933, we installed a 42-in. bypass sewer, which was approved by the State Department of Health, and when the sewer flow exceeds 2,000,000 gallons it spills over the weir instead of going to the Imhoff tanks. The overflow is treated with chlorine. Tests for residual chlorine are made about 500 ft. from the chlorinator building.

The new covered sludge bed is 234 ft. by 50 ft. in plan and has an area of approximately 10,000 square feet. It is divided by baffle walls into four

equal beds 50 ft. × 50 ft. in plan, of the hill and valley type construction. The drainage is collected in halved 6 in. V-tile. The filtering material consists of from 12 in. to 18 in. of graded gravel over which 3 in. of sand is spread.

The sludge from the Imhoff tanks is pumped to the sludge beds with a 5-inch Taber pump about 10 ft. below the ground. The sludge is introduced to the beds by two lines of 8-in. cast iron piping running the full length of the building. They are about 18 ft. apart and about 11 ft. from the side walls. There are four valve openings for each bed, also a walk the full length of the building, which makes it very handy to get the measurement of the sludge.

We made 10 cleanings from the sludge beds during 1932 and the drying time was from 14 to 18 days in warm weather and about 4 to 5 weeks in the winter months. We pump the sludge about 12 in. deep and when it has dried to about 75 per cent moisture there is about 5 in. and practically no odor. The sludge is removed with seven-tine forks. It takes about $3^1/_2$ days to clean out the sludge and requires the services of 6 laborers.

The sludge house is equipped with an overhead Louden Conveyer System which consists of 3 rails and 2 buckets over the center of the sludge beds. The sludge when pumped into the beds is comparatively dark in color (gray) and very fluffy with a gassy odor. It takes about 100 tons of fine sand and grit to cover the sludge beds 3 in. deep.

Comments on Operation and Design of Sludge Beds from an Operator's View-point.—The operating handles for the vents in the glass structure are not always located where they can be reached without stepping into the sludge.. We have had to build extra walks in some cases in order to reach these points. I have also noticed this fault in other beds than our own. It would be most desirable to have the point of operation located in a place convenient and easy to reach.

The valves used on the outlets of the sludge piping in this plant open completely with a quarter turn. They have proved very satisfactory.

The metal parts inside and out of the sludge beds have been painted with an acid-resisting aluminum paint which has also proved most satisfactory.

The structure has been painted over a year and looks good at all times.

Due to certain exterior conditions, the concrete walls around the sludge beds rise about 2 ft. 6 in. above the maximum sludge level.

Adjacent to the wall where the shadows are cast the sludge dries more slowly. If it were possible to bring the solid wall down closer to the maximum sludge line the bed would be more efficient.

When sludge is pumped on the beds we open the vents in the side walls and also at the top. As the drying proceeds and the sludge becomes

partially dry, we close the vents at the top and use only the vents on the side walls. In this way the heat is retained and the sludge dries faster.

The amount of sludge drawn from this plant during the year 1932 from January 28 to December 23 was as follows:

Total amount of sludge drawn from the 4 Imhoff Tanks, 100,000 cu. ft.

Total amount of sludge removed from drying beds, 37,024 cu. ft.

This shows about 63% reduction in volume.

The sludge is very stable and gives no offensive odors.

The pH values for the sludge in the various tanks during the first four months of 1933 were as follows:

	Jan.	Feb.	March	April
Tank No. 1	6.9	7.0	7.2	7.6
Tank No. 2	6.9	7.1	7.2	7.2
Tank No. 3	6.8	7.0	7.0	7.3
Tank No. 4	6.8	7.0	7.2	7.1

Sludge Disposal at Town of Tonawanda, Plant No. 3

The Town of Tonawanda Sewage Treatment Plant No. 3 at Ellicott Creek consists of bar gratings, pumping station, Imhoff tank, dosing tank and trickling filters. The effluent from the trickling filters is discharged into Ellicott Creek.

The plant is designed on the basis of serving 5000 people, of which approximately 2500 are being served at the present time.

The sewage may be diverted either to one or both of two 48-in. branches, which contain an electrically operated gate valve. From these branches the sewage passes first through bar gratings with 1-inch openings, and thence to the wet wells. The wet wells are interconnected by an opening in the division wall provided with a gate valve. Thus the wells may be used as one well or separately. The two 8-in. vertical pumps are located in a dry pit at the same elevation as the wet wells. They are float operated.

The sewage is pumped to an elevated so-called distribution chamber in which there are bar gratings with 1 inch openings. From this distribution chamber it flows directly into the longitudinal Imhoff tank, which is also elevated above the ground surface. After passing the Imhoff tanks, the sewage passes into a single dosing tank, which is equipped with a single siphon serving the two filter beds.

The filters are in two units draining toward a central open effluent channel. The filter beds are 156 ft. × 89 ft. in area and consist of 6 ft. of crushed, hard limestone. The sewage is distributed by means of square spray nozzles. The underdrains are of the half tile type.

There is a 4-in. pump installed in the sludge line and the sludge is discharged upon a sludge bed 71 ft. × 71 ft. in area.

The filter material on the bed consists of 2 in. of mortar sand on the top, then 3 in. of $^1/_{16}$ to $^1/_4$ in. gravel, or 4 in. of $^1/_2$ to 1 in. gravel and 9 to 19 in. of 1 to $2^1/_2$ in. gravel or broken stone on the bottom, the thickness depending on the construction of the hill-and-valley type floor. The underdrains consist of 8 lines of 3-in. drain tile, laid on the filter floor, and drains into a 6-in. open joint V-tile running into the drainage channel of the trickling filter.

The sludge is removed from the beds by a Louden overhead conveyer system, with two tracks in each bed. The dry sludge from this plant is used in the town parks as a fertilizer.

The sludge which is produced in this plant is less than in plant No. 2, because there are so few people contributing sewage, and the proportion of sanitary sewage to storm sewage during the larger part of the year is very low.

The following figures show the degree of reduction of volume of sludge. The total sludge drawn from the Imhoff tanks in 1932 was 50,410 cu. ft. The dried sludge removed from the sludge bed was 12,393 cu. ft. This gives a percentage reduction of 75 per cent.

In the operation of the bed, it has been found necessary to clean out the underdrains from time to time. To avoid this I suggest that in the design it would help the operator to have the tile open at both ends to permit rodding. The sludge from this plant has proved satisfactory.

The Selection and Maintenance of Mechanical Sewage Equipment*

BY JOHN LEWIS

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The proper selection of mechanical sewage equipment and its maintenance after installation is most important if continuity of operation is to be achieved. This fact may seem obvious and yet there are in existence many installations where greater attention to detail when the specifications were written and the layout planned would have produced more satisfactory results and saved the large amount of money afterward expended for necessary repairs. In this respect, Rochester is no exception.

The city has in service nine sewage lift stations and four treatment plants, pumping and treating upward of sixty million gallons of sewage per day. Naturally, these plants comprise considerable mechanical equipment. To mention just a few of the different kinds of apparatus—there are fine sewage screens; hydraulic turbines; air compressors of various types; and trash pumps varying in size from three to ten inches. These units, together with reducer drives; electric motors and their control apparatus; and electric generators and locomotives, require constant maintenance and repair. A brief summary of the difficulties encountered in their operation should be of interest to operators elsewhere.

Beginning with the lift stations, these installations with three exceptions are equipped with non-clogging sewage or trash type pumps. The designation "non-clogging" is not strictly correct because this type of pump will clog. Even though such difficulty may occur at infrequent intervals experience has shown that it is essential to place handholes on both the pump volute and suction elbow. In horizontal units it is also desirable to provide a split casing. At Rochester all pumps are equipped with anti-friction bearings. Renewal of these bearings has been frequent, due to condensation of moisture within the housings. On the high speed units, it has often been necessary to replace shaft wearing sleeves. Sewage carries considerable sand and other gritty material and no packing has yet been found which will eliminate "cutting." In spite of difficulties mentioned the operation of the pumps has been fairly satisfactory.

Performance of intermediate shafts and couplings; electric motors; and particularly motor controls, was poor until these parts were rebuilt or replaced. At one of the stations the windings of three motors were

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burned out within about fifteen months. The original motor control was discarded and a second make and type substituted. Within a few months, this apparatus was removed and a third type installed. The control now in service is functioning in a satisfactory manner. The difficulties encountered in the operation of the motor controls at this and other stations indicate that magnetic contactors, especially with "across-the-line" starting conditions, should have a carrying capacity of three to four times the full load current. Provision should also be made against single phase operation of motors by the installation of "open phase" relays. With motor control of larger capacity and with "open phase" relay protection, the operating troubles experienced here would not have occurred and many dollars would have been saved.

The size (diameter) of intermediate shafts; the type and spacing of bearings; and the type and number of flexible couplings is also an important consideration in the design of vertical pumping units. At the station previously mentioned, it was necessary to install larger intermediate shafts and bearings; to re-arrange spacing of bearings; and to provide additional flexible couplings before satisfactory operation was attained. Yet the original design was practically in accord with the manufacturer's recommendations.

In rebuilding equipment for the stations where vertical pumping units are used, the intermediate shafting, bearings and couplings are now arranged so that the upper housing and impeller of the pumps can be removed without disturbing the motor and its supporting base and the greater portion of the shafting below the driving unit.

All of the sewage lift stations at Rochester operate under conditions of intermittent duty. Float control of the pumps is employed at several places and at the other locations air pressure control is used. The latter method has proved excellent where the distance between the high and low water level in the suction well is large and a slight variation between the starting and stopping points allowable. However, where the differential in the suction well is small and close regulation desired, float control appears to be the most satisfactory method.

Another difficulty encountered at all the stations where units are placed below grade is the corrosion of conduit and conduit fittings and breakdown of the insulation of electrical conductors. Where it was feasible to do so, replacements have been made with hot-dipped galvanized conduit and conduit fittings of the gasketed type and lead-covered conductors. While the first cost is higher, nevertheless the additional expenditure is justified on the basis of continuous operation and possible damage to expensive electrical equipment.

Motors should be built with "moisture-proof" or special insulation and a splash-proof enclosure. Totally enclosed motors have not been found

satisfactory because condensation of moisture will occur within the closed housing. Free ventilation apparently prevents such condensation even though the surrounding atmosphere is very damp and the saturation high.

Turning to the operation of the mechanical equipment at the treatment plants, the most difficult problem has been the rebuilding of the 100 hp. hydraulic turbines at the Irondequoit Plant. The units were designed for operation with clear water rather than sewage. A great deal of money has been expended to overcome the erosion and corrosion of the various parts and the work of reconstruction has been carried out almost piece by piece during the past six years. It was discovered that high chromium-silicon iron will withstand the attack of the hydrogen sulphide gas and sulphuric acid and this material was used in the manufacture of the new parts. Other difficulties encountered in the operation of the mechanical and electrical equipment at the treatment plants were due in most cases to the same causes as mentioned for the lift stations.

It is not within the scope of this brief paper to elaborate on the many details as regards maintenance. However, from this standpoint, the most important consideration is that of lubrication. Again, experience has pointed out that "cheap lubricants are most expensive in the end."

Thousands of dollars have been spent at the local plants in rebuilding equipment of all kinds, this work being made necessary either through the use of a poor grade of lubricant or, in some cases, failure to observe that the bearings were not receiving lubrication. These difficulties have now been largely overcome; first, by insisting on the purchase and use of high quality of lubricant; and second, making the lubricating systems accessible so that they will receive proper attention. Lubricating conditions have been improved through the application of high pressure grease systems and accepting the advice of a lubricating specialist. As a general proposition, grease is better suited to the various conditions than oil. The grease, however, must be compounded to meet the conditions and it should be of a kind which will not saponify when moisture is encountered and oil and filler separate when forced through a high pressure system.

Much of the older equipment now in service at Rochester was not provided with renewable bearings. During the past ten years, these units have gradually been rebuilt with such bearings at a large expense. Obviously, their installation in the beginning would have greatly reduced the cost of replacement.

In conclusion, it is worthy of emphasis that mechanical sewage equipment should be selected on the basis of three important factors; first, simplification, which will reduce the number of moving parts to a minimum; second, durability, which implies strength and especially ability to withstand conditions of erosion and corrosion; and third, accessibility, which will insure proper maintenance after operation begins.

Sewer Construction Using Welfare Labor*

BY F. W. HALEY

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This paper describes the results accomplished at Marblehead, Massachusetts, using unemployed citizens of the town to construct necessary extensions to the sewerage system, aggregating somewhat over four miles and including approximately 8000 feet of main sewer.

All of the construction actually done would have been undertaken in the near future in any event and the main sewer construction, which made up 37 per cent of the total length, was needed as an outlet for the rapidly growing so-called Clifton District of the town.

Marblehead is essentially a summer resort town, with a resident population of 8668 persons, which population has been estimated to double during the summer months.

Unemployment in the town reached a point in 1932 where it was estimated that between 200 and 300 able-bodied men were unable to find work during the summer months, when work is usually available, and about 70 of this number had been forced to seek welfare aid.

The local welfare department dispenses aid in the form of orders for groceries and fuel to the extent of an equivalent value of $7.00 for the average family per week. There were less than a half dozen cases where an equivalent of $15.00 per week was dispensed to any one head of a family.

A special town meeting was held in July, 1932, and at this meeting $110,000 was appropriated to be expended under the direction of the Sewer Commissioners for the construction of additional sewers, and it was further "resolved" that the work should be done by welfare labor, citizens of the town—that the rate of pay should be 40 cents per hour—and that all supplies, so far as possible, should be purchased through competition among Marblehead business men.

The Sewer Commissioners accepted the imposed duty of providing work for the unemployed, but took a definite stand that the prime objective from its standpoint was the building of sewers at the lowest cost possible under the imposed conditions. It was agreed that no machinery other than air compressors, trench pumps and concrete mixers would be used and that all excavating and backfilling of trenches and driving of sheeting would be done by hand. Otherwise the job must be organized for efficiency, and a reasonable output of work, commensurate with the physical capacity of the men employed, would be required.

It was recognized that many of those seeking employment could not

* *Presented at the Spring Meeting of the New England Sewage Works Association, Woonsocket, Rhode Island, May 1, 1933.*

work efficiently on sewer construction for eight hours each day and it was felt that continuous contact with the work was essential to keep up the morale of the workers, so it was decided to shift the gangs at noon, except for a few of the more skilled workmen who were used in pipe laying and other particular activities.

This method provided 24 hours work each week per man and with a labor wage rate set by the commissioners at 50 cents per hour, $12.00 a week was paid. Wages were paid in cash and it is believed that this was an important element in keeping up the interest of the men. When a man works productively, he is entitled to cash payment for his work, which may be expended as he sees fit. Through coöperation with the Welfare Department, however, no able-bodied men have been given direct aid since the sewer construction started.

Applications for work were immediately received by the commissioners and the offer of the engineer retained for the design and construction of the system to superintend the proposed work without extra cost to the town was accepted. Young engineers, residents of the town of Marblehead, were selected for foremen and all labor employed was certified by the local welfare board.

Work was started August 12, 1932, and continued without interruption, except for interference by unfavorable weather, until February 21, 1933, 153 out of a possible 164 days having been worked. At the start, 100 men were employed, 50 in the morning and 50 in the afternoon, divided into two gangs. On August 18 the number was increased to 150 men by addition of a third gang and from October 17, when a fourth gang was organized, approximately 250 men were employed until February 7, at which time all except men who had been receiving welfare aid previous to the start of the work were let go. The construction was completed, using only the men whose names had previously been on the welfare list.

Four and one-tenth miles of sewers were constructed, ranging in diameter from 8 inches to 15 inches. Some 10,000 feet of underdrains were necessary on account of ground water conditions encountered. Continuous pumping throughout the work was made necessary by the high level of the ground water encountered and asphalt jointing compound, poured hot, was used in all the sewers constructed. The average depth of sewer trench was approximately nine feet and subsoil conditions were such as to require close sheeting of the trenches for approximately 43 per cent of the total length. The main sewer and all sewers 10 inches in diameter and larger were laid in a concrete cradle as a protection against possible breakage due to weight of backfilling, and 450 cubic yards of plain concrete were required for this purpose.

Only 56 cubic yards of ledge rock were encountered in the construction,

which, with the addition of a few boulders, made the total rock excavation exceptionally small for work in Marblehead.

Brick masonry in manholes was laid by local masons. All construction materials, with the exception of sand and gravel, were purchased through local agencies, and Marblehead contractors drilled and blasted the ledge rock encountered. All trucking was done by local concerns.

The work has been carried out with only minor accidents to the men employed; about 50 accidents occurred which required medical attention of a minor nature, and only 20 per cent of this number were of sufficient seriousness to warrant the payment of compensation by the insurance company.

An effort was made to utilize the unemployed labor efficiently and to construct sewers at the lowest cost possible under the imposed conditions. The results accomplished have been satisfactory, not only in point of cost of the work done, but in the relief of unemployment and in reduced outlay in the Welfare Department. Of the total Sewer Department labor payroll of something over $60,000, 27 per cent, or $16,000 has been paid to men who were actually receiving welfare aid at the time sewer construction was started. It is estimated that if sewer work had not been undertaken, necessary aid to other men who had been employed would have added as much more to the welfare outlay, and that in total the construction of sewers by the unemployed has saved to the Welfare Department an expenditure of between $25,000 and $30,000.

As previously stated, the only machinery used on the work has been air compressors, trench pumps and concrete mixers, all excavation having been done by hand. The total expenditure, including engineering fee, was $105,000. The total value of materials, equipment, etc., on hand at the completion of the work equalled $2800, making the net cost of the work done approximately $102,000, of which $62,250, or 61 per cent, has been paid out to Marblehead citizens for labor.

It is interesting to note that of the total of 250 men employed, not more than 50 have been of the unskilled labor type, accustomed to heavy work. The remainder constitute an average occupational cross-section of a town of this nature and included 24 shoe-workers, 20 clerks, 13 seamen, 9 carpenters, 7 truck-drivers, 6 painters and blacksmiths, plumbers, mechanics and a real estate agent, barber, sales manager and an actor.

The question naturally arises as to the increase in cost of this method over contract work done with modern machine equipment. It is estimated that the cost of the 4.1 miles of sewer constructed, if let by contract, would have approximated $85,000, or $20,000 less than the actual cost. This excess cost of 23.5 per cent is equal to about 65 per cent of the estimated savings in welfare disbursements. In other words, the town, by use of unemployed labor, has constructed 4.1 miles of sewers with some $10,000

less total expenditure than would have been required for construction by contract, plus the probable outlay of the Welfare Department, if the unemployed had not been used in the construction of sewers. There is also to be taken into account the opportunity for work afforded to other citizens whose names would not have appeared on the welfare lists, but who have needed the income obtained from the sewer construction.

The relatively low cost of the work has not been due to any particular fitness of the local labor for construction work, but rather the insistence that, while the work was to be made a means of relieving unemployment, the controlling condition in the operation should be the construction of sewers as economically as possible by good organization and capable supervision.

It is believed that a major factor in the efficiency of labor unaccustomed to heavy work has been the limiting of daily work period to four hours for each man. It is probable that 75 per cent as much work can be done in 4 hours by such labor as in eight hours. Obviously, limiting the day's work to four hours has doubled the number of men to whom wages were made available from the money appropriated for sewer construction.

Another important condition in the success of the undertaking has been the fact that the workers knew that they were building necessary sewers and not simply putting in time on some kind of work which, except to relieve unemployment, would not have been undertaken.

Incineration of Skimmings*

BY A. P. BANTA

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This paper supplements the paper presented by A. M. Rawn at the Yosemite meeting in May, 1932, on the digestion of bar screenings at the Joint Disposal Plant of the Los Angeles County Sanitation Districts. (Published in THIS JOURNAL, Vol. 4, p. 982, November (1932).) At that time the skimmings from both the primary and final clarifiers were being disposed of by digestion in the main digestion tanks together with the primary and excess activation sludge. The experiments on the separate digestion of bar screenings and skimmings were then in progress.

Increasing difficulty was experienced in drying the sludge from the main digesters. The sludge, when placed on the beds, had a slimy, mushy, dull appearance and failed to give up its water readily, either by percolation or by evaporation. Additional digestion time was provided in a lagoon with the belief that the digestion time was too short, but the added capacity made no appreciable improvement in the drying qualities of the sludge. The practice of digesting the screenings in the same tanks with the raw and activated sludge from the main plant was then discontinued. This latter move proved to be the key to the difficulty. The drying quality of the digested sludge improved gradually as the skimmings were displaced from the digestion cycle. The press for sludge drying space was relieved and this phase of the problem was solved.

It was now necessary to find a separate means of disposal for the skimmings, which amount to 4300 pounds per day with a moisture content of about 80 per cent. The ether soluble content on the dry weight is 33 per cent and the volatile content is 78 per cent. The quantity and quality of the skimmings vary from day to day and since it is difficult to get either an average sample or an accurate analysis, the figures given are at best approximate. At times analysis has shown an entire absence of mineral oil. In general it may be said that the mineral oil content is much less than would be expected from a sewage coming from an area with many factories, service stations and garages. Occasionally large quantities of crude or light oil are received for short periods, but these occasions are becoming less frequent due to corrective measures which are being enforced at the known sources. When oil is received, it is skimmed from the tanks and burned in an open pit.

Tank space of sufficient capacity for disposal of the skimmings by separate digestion was not available. Alternative methods were considered. Finally, incineration at high temperatures was considered the

* *Presented before the Fifth Spring Conference of the California Sewage Works Association, San Luis Obispo, May 5, 1933.*

most likely solution. An ample supply of gas from the digestion tanks was available for fuel. An experimental incinerator 4 feet by 10 feet in plan and 5 feet high was built of common brick with the roof arched, and a 15-foot steel stack was provided. Local brick mud was used in the joints between the brick.

The incinerator was divided into two compartments by a solid steel plate $^1/_2$-in. thick, and gas burners were placed in the side and front of both upper and lower compartments, the idea being that the skimmings would be placed in the upper compartment and receive heat both from the upper burners and from the conduction through the steel plate. The burners in the lower compartment served not only to apply heat to the lower surface of the skimmings, but also to provide additional combustion in the lower portion of the stack for any odor-producing fumes which might escape from the upper compartment. This indirect-direct firing appears to offer a considerable advantage and safety factor.

The skimmings are prepared for incineration by draining on sand beds. The daily catch is placed on the beds and removed the same day so that the draining time is not long enough to produce putrefactive odors. The beds have an area of about 500 square feet. The skimmings, when drained, are taken from the beds with a manure fork and placed in the upper compartment of the incinerator. The moisture content of the material as it is removed from the beds is about 50 per cent. The charging is done gradually so that a portion of the charge is always dry and burning. If the charging is done too rapidly, the temperature of the fire-box is reduced so that the combustion is incomplete and smoke is produced. Subsequently a forced draft was provided because of the large amount of air necessary to support the combustion of this rich material. By varying the forced draft, it was possible to make the interior of the fire-box white hot, so that the brick material of the top and sides began to flow. At this high temperature, about 2000° F., and at the usual operating temperatures, estimated at 1700° F., the combustion takes place in a very satisfactory manner. No smoke is produced and no definite or objectionable odor is noted. A fire-box lined with fire brick would withstand a temperature of 2700° F., and an operating temperature of about 2400° F., and the operating standard could be maintained uniformly. With the experimental set-up, the temperature is not high enough to permit the building up of sufficient heat reserve to prevent occasional smoke production due to rapid charging. The smoke produced on these occasions is dense and black and has an odor very similar to that produced from soft coal, but it is not objectionable.

After a charge has become dried out it contains more than enough fuel value to support combustion. The temperature of operation at this point can be controlled by varying the quantity of forced draft, and the

gas may be turned off. It is necessary to rake the burning surface so as to expose new portions for combustion. In the initial stage after self-supporting combustion is established, the mass becomes semi-fluid due to the melting of greases and fats which are in the solid state at ordinary temperatures. In the latter stages of burning, the material assumes the appearance of burning rubbish. The end-product is a small volume of inert granular ash of which a large portion is sand, picked up on the draining beds. The reduction in volume is something more than 95 per cent and the end product presents no disposal problem.

The experimental incinerator has taken care of the entire production of skimmings for about six months. A rancid grease odor in the immediate vicinity of the incinerator due to droppings during the charging operation has been minimized by care in operation. While the incineration proper has not been odorless, the odors produced are not objectionable or persistent. The measure of success achieved by this method of disposal is probably due, in the case under discussion, to the high grease and volatile content of skimmings.

Detection and Measurement of Certain Types of Gases*

BY S. H. ASH

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The Bureau of Mines has investigated matters involving the source, properties and physiological effects of gases, and has developed methods of detection and safeguarding against gases encountered in the exploitation of the mineral kingdom. Extensive studies have also been made of gases involved in the ventilation of vehicular tunnels,[1] the driving of aqueduct tunnels[2] and of gases in manholes.[3]

This paper comprises a general description of the detection and measurement of gases that may be of interest as they apply to problems that may be encountered in the field of sewage treatment.

The term "gas" has a rather broad meaning, but in the average individual's mind it usually means anything of an invisible gaseous nature other than pure dry air,[4] which is described by Rosenau. Normal air[3] contains the following gases:

	Per Cent by Volume
Carbon Dioxide	0.03
Oxygen	20.93
Nitrogen	79.06

A sufficient amount of oxygen must be present in respirable air in order that the lungs may contain as residual air about 15 or 16 per cent of oxygen and between 5 and 6 per cent of carbon dioxide. For the best physiological effects the amount of oxygen present, whether in normal air or in the presence of pure oxygen, is obtained by controlling the amount of oxygen present to bring the equivalent partial pressure[5] of the inhaled oxygen to normal (20.9 per cent) at sea level.

The number of lives lost annually on account of what is usually classed as "asphyxiation" or "overcome by gas" is particularly noticeable, and such accidents are usually traceable to nothing more than a deficiency of oxygen in the atmosphere breathed. Oxygen is necessary for the support of life and of combustion. It is colorless, odorless, tasteless, non-poisonous, and the most important to man of all the gases in the air. However, it may be dangerous to breathe pure oxygen at a pressure much higher than 15 pounds per square inch. The effects of a deficiency of oxygen are physiological and progressively dangerous as the percentage of oxygen is reduced below that found in normal air. This is particularly noticeable

* *Presented before the Spring Conference of the California Sewage Works Association, San Luis Obispo, May 5, 1933.*

in ranges below 17 per cent, becomes aggravated at 15 per cent, affecting the heart action, and may become decidedly dangerous when the percentage drops below 13 per cent, at which point an acetylene flame, if introduced, will be extinguished.

In the order of their desirability and safety factor the agencies that may be used for the detection of a deficiency of oxygen are the flame safety lamp, the candle, and the flame of a carbide lamp. The flame of a flame safety lamp or candle is extinguished at about 16.25 per cent oxygen, and the flame of a carbide lamp at about 12.5 per cent.[6] An atmosphere known or supposed to contain a deficiency of oxygen only should not be entered except by a person aware of the dangers and provided with a flame safety lamp or a candle. When these agencies fail, entry should be made only by qualified persons wearing self-contained oxygen breathing apparatus, or hose masks, in certain situations. The procedure to follow and the method of using the foregoing accessories will suggest themselves in the hands of qualified persons.

Due to the fact that the other two gases, nitrogen and carbon dioxide, as they exist in normal air, do not create any physiological effect when normal air is breathed, they will be discussed in their order as they may occur in abnormal situations. Normal air in its course of use or travel becomes contaminated and changed, creating atmospheres that may be explosive or otherwise dangerous to life, either through becoming deficient in oxygen or poisonous to the human system.

There are certain gases inherent in the processes involving the disposal of sewage. Studies[7] have been made by the Bureau of Mines to determine certain conditions in sewers, not only as regards the composition of manhole atmospheres from the standpoint of explosive hazards, but also with regard to the safety and health of workmen who may have occasion to enter manholes for inspections and making repairs. There is little information available with reference to the composition of manhole atmospheres.

In a study[3] of gases in manholes in the City of Boston, Jones classes the constituents present in manhole atmospheres as gases showing three kinds of contaminations:

1. Gases containing hydrogen, carbon monoxide, illuminants, methane and ethane. Because of the presence of hydrogen and carbon monoxide these contaminations were attributed and usually proved to be manufactured gas, which found its way into manholes from leaks in gas mains, services and other sources.

2. Gases containing abnormally high percentages of carbon dioxide, varying amounts of methane and low percentages of oxygen. These mixtures usally offered no special hazards from explosions. Most of these mixtures were found to be non-explosive either when air or when combus-

tible propane gas was added. In the past these mixtures have been termed "sewer gas" for the want of a better name, because such mixtures are often found in sewer atmospheres. Many of these mixtures contain rather large percentages of methane as the result of fermentation or decomposition products of organic material in the soil.

3. A few of the samples showed the presence of heavy hydrocarbon vapors. When these heavy hydrocarbon vapors were found in manhole atmospheres, they were always associated with other combustibles such as those from manufactured gas or soil gas, and in no cases were these vapors present in amounts sufficient to produce explosive mixtures.

Contamination from more than one source was found in most of the samples analyzed, so that there usually was no sharp dividing line between the three classes.

An inspection of many samples shows a wide range in the composition of the gases found in the manholes, as follows:

	Per Cent by Volume
Carbon Dioxide	0.0 to 16.6
Illuminants	0.0 to 3.9
Oxygen	1.0 to 20.5
Hydrogen	0.0 to 20.5
Carbon Monoxide	0.0 to 3.8
Methane-Ethane	0.1 to 34.7
Gasoline Vapor	0.0 to 0.6
Nitrogen	30.6 to 83.7

The foregoing and other gases that may be encountered in varying amounts are briefly described.

Carbon dioxide, which is heavier than air, has long been used as a measure of the impurity of air, but its importance as such has probably been overemphasized. It is normally a product of the decomposition and combustion of organic compounds and also of the respiration of men and animals. It is a colorless and odorless gas, but when breathed in large quantities may cause a distinctly acid taste. It will not burn or support combustion. It has been found emanating from the rock strata in underground workings of certain mines, or can be expected to be encountered in limestone regions, particularly where high temperatures are involved.

Physiologically it acts directly on the nerves of respiration. One-half of one per cent (0.5) of carbon dioxide in normal air causes a slight increase in the lung ventilation; that is, a man exposed to this percentage of carbon dioxide will breathe a little more deeply and a little faster than when in pure air. If there is 2 per cent of carbon dioxide in the air, the lung ventilation will be increased about 50 per cent; if 3 per cent, about 100 per cent; if 5 per cent, about 300 per cent, and the breathing is laborious; and if 10 per cent, it cannot be endured for more than a few minutes. Carbon

dioxide in air has these effects when the oxygen content remains about normal and the subject is at rest. Under conditions of action or exercise the symptoms are intensified and the danger is greater.

Illuminants present a dangerous factor as a constituent of manhole atmospheres on account of the very definite hazards connected with the toxic and explosive characteristics of such gases. They can be broadly defined as that group of unsaturated hydrocarbons that can be absorbed by fuming sulphuric acid. The percentage present will depend upon the source. Illuminants are particularly dangerous where carbureted water gas is involved. This gas contains a high percentage of ethylene in particular. Further, illuminants should be suspected when other gases such as carbon monoxide are present and indicator tests or apparatus, calibrated for illuminants on the principle of those used for gasoline vapors, can be utilized.

Hydrogen is colorless, odorless and tasteless. It is produced by manufacturing processes, incomplete combustion in explosions, mine fires and firing blasting explosives. It weighs only 7 per cent as much as air. Air that contains 4.1 to 74 per cent of hydrogen will explode violently if ignited. Hydrogen in air will explode when the oxygen content is as low as 5 per cent.

Carbon monoxide is a product of the incomplete combustion of carbonaceous materials. The gas is colorless and therefore invisible. Generally speaking, it does not support combustion and cannot be detected by a flame safety lamp until the concentration becomes so high that persons without respiratory protection would be overcome almost immediately. It is lighter than air. Carbon monoxide is produced by manufacturing processes, and it is found during mine fires, in explosions of gas or coal dust and in blasting or in the burning of explosives. It is the dangerous constituent of manufactured gas and the exhaust of automobiles. Air that contains 12.5 to 74 per cent of carbon monoxide will explode if ignited. Carbon monoxide in excess of 0.01 per cent may, if breathed, eventually produce symptoms of poisoning, and 0.02 per cent will produce slight symptoms in several hours. When 4 parts in 10,000 (0.04 per cent) are present and the exposure is for 2 or 3 hours, headache and discomfort usually occur. When 0.12 per cent is present it will produce slight palpitation of the heart with moderate exercise in 30 minutes, a tendency to stagger in $1^1/_2$ hours, and confusion of mind, headache and nausea in 2 hours. According to W. P. Yant, Pittsburgh Experiment Station, U. S. Bureau of Mines, a concentration of 0.20 to 0.25 per cent will usually produce unconsciousness in about 30 minutes. Its effect in high concentrations may be so sudden that a man has little or no warning before he collapses. Henderson[8] explains and also discusses the dangers of carbon monoxide.

Carbon monoxide exerts its extremely dangerous action on the body by displacing oxygen from combination with the hemoglobin of the blood, which normally absorbs oxygen from the air in the lungs and delivers the oxygen to the different tissues of the body. The affinity of carbon monoxide for hemoglobin is about three hundred times that of oxygen. Because of this, even when only a small amount of the poisonous gas is present in the air breathed into the lungs, the hemoglobin will absorb the carbon monoxide in preference to the oxygen that may be present.

The rate at which a man is overcome and the sequence in which the symptoms appear depend on several factors: the concentration of gas, the extent to which he is exerting himself, the state of his health and individual predisposition, and the temperature, humidity and air movement to which he is exposed. Exercise, high temperature and humidity, with little or no air movement, tend to increase respiration and heart rate and consequently result in more rapid absorption of carbon monoxide. A few persons may develop a tolerance for carbon monoxide and may after a while be able to "stand" more of the gas than when first exposed to it. It may also follow that after a period of tolerance there will be a break in the compensating factors, and the person will become more susceptible. The symptoms of chronic carbon monoxide poisoning are a tired feeling, headache, nausea, palpitation of the heart and sometimes mental dullness.

Although carbon monoxide poisoning may be either acute or chronic, depending on the concentration and period of exposure, interest usually centers in the treatment of the acute form.

In the treatment of the chronic form of poisoning the most important factors are avoiding further exposure to carbon monoxide and taking a thorough rest. In the treatment of acute carbon monoxide poisoning the most important thing is to get the gas out of the blood as rapidly as possible, thus decreasing the possibility of serious after-effects or even loss of life through failure of the heart and of respiration. As soon as the victim begins to breathe air in which there is no carbon monoxide the process of eliminating the CO from the blood will begin. However, this normal elimination is slow, requiring possibly 8 to 15 hours to reduce the saturation to 10 per cent, and often has serious effects. Inhalation of pure oxygen will remove the carbon monoxide from the blood four to five times as fast as will normal air, while a mixture of 5 per cent of carbon dioxide in oxygen will cause increased lung ventilation and remove the carbon monoxide five or six times as fast as normal air. The advantage in the use of oxygen alone is that it is more available, owing to its wide use in industries for other purposes. Both of these inhalation treatments are given preferably with an inhaler, in conjunction with artificial respiration (Schaefer method), but the oxygen or carbon dioxide-oxygen mixture may be given by improvised apparatus or sprayed directly from the tank over

the patient's face when an inhaler is not at hand. Caution should be observed in controlling the flow when using the gas direct from a tank.

Methane, also known as "marsh gas" and "carbureted hydrogen," is the chief constituent of explosive mine gases, sewer gas and natural gas. It is lighter than air. It is colorless, odorless, tasteless, inflammable and nonpoisonous. In metal mines and tunnels methane is frequently found in tunneling through carbonaceous shales. Its common occurrence and explosibility when mixed with air are directly or indirectly responsible for numerous disasters and explosions in mines and tunnels as well as in connection with the use of natural gas. Methane has no direct physiological effect upon humans, but it may accumulate to an extent that will dilute the oxygen of the air to an amount sufficient to cause a person to suffer from oxygen deficiency. Several deaths by asphyxiation have been caused by persons unknowingly entering high concentrations of methane. Air that contains 5 to 15 per cent of methane will explode if ignited.

Ethane, and other heavier members of the methane or paraffin series, are components of natural gas, but are not normally found in mining practice. They tend to increase the explosibility but are usually not present in amounts large enough in themselves to be dangerous, or even to be easily detected, unless gasoline vapors are involved. Air with 3.2 to 12.5 per cent of ethane is explosive.

Nitrogen is the principal component of normal air. Accumulation above the normal amount in air is due chiefly to the removal of oxygen from the air by absorption. It is slightly lighter than air and is not combustible and will not support combustion. Nitrogen is physiologically inert and is harmless to man. It has no effect other than to act as a diluent of the oxygen in air.

Katz and Bloomfield[9] have thoroughly discussed the dangers from gasoline and petroleum vapors. Vapors of petroleum, gasoline and other products of petroleum cause anesthetic effects when inhaled. Some petroleums contain in solution hydrogen sulphide gas, which is exceedingly poisonous, and when breathed quickly causes unconsciousness and death. This exceedingly dangerous gas is heavier than air and has a very disagreeable odor (like rotten eggs) when greatly diluted by air. At higher concentrations the gas paralyzes the sense of smell. Six hundred parts per million (0.06 per cent) in air renders a dog unconscious in 2 minutes and kills it in about 15 minutes. It causes temporary blindness in concentrations as low as 1 to 2 parts per million. Its explosive range in air is from 4.3 to 46 per cent. Its lack of odor in deadly concentrations makes hydrogen sulphide very treacherous. It has killed a number of men, and an atmosphere containing it should not be entered without proper protective equipment.

Experiments[10] have shown that the odor of gasoline is noticeable in inhaled air containing 0.03 per cent gasoline. In percentages ranging from 0.07 to 2.6 per cent the effect is dizziness to collapse, in a range of from $14^1/_2$ minutes to a matter of taking 10 to 12 breaths. The stage between unconsciousness and death is very narrow, making the vapors of the higher hydrocarbons dangerous anesthetics. High concentrations quickly overcome a victim, causing complete insensibility and then death. On account of the foregoing hazards, atmospheres containing gasoline vapors are exceedingly dangerous, and because of the penetrating qualities of gasoline vapors protective equipment for wearers should be used with extreme care and caution, and such equipment should be selected intelligently.

In a study[11] of the subjcet it was concluded that the explosive effect of gasoline vapor in sewers is largely localized, and even with the explosive limit taken as 1.5 per cent in air, this condition would be rarely encountered (also see table on page 669). The dangers lie more in the extremely dangerous toxic effects of gasoline vapors, and its participation as an explosion factor with other explosive gases.

Methods of Detecting Common Gases

Various methods[5] and devices are in use for detecting common gases. The detection of black damp (a mixture of carbon dioxide and nitrogen in air) or an atmosphere deficient in oxygen, methane and carbon monoxide is of primary importance under most circumstances.

Other gases that may be found in mines, tunnels, aqueducts, etc., such as hydrogen sulphide, oxides of nitrogen and sulphur dioxide, usually occur in small quantities and unless present in amounts large enough to be detected by smell require collection and the analysis of air samples. The collection and analysis of these gases require special processes entirely different from the usual procedure in analyzing ordinary gases; therefore a chemist of considerable experience should perform the work.

Detection of Methane

There are five generally accepted methods[5] for detecting methane. Four of these use devices that can easily be taken to the point of sampling, and the other is ordinarily used at some outside point. These methods are:

1. Use of a permissible or approved flame safety lamp.
2. Use of an approved Burrell indicator for combustible gases in air.
3. Use of an approved Martienssen methane detector.
4. Use of an approved Union Carbide Co. methane-indicating device.
5. Collection of air samples and determinations of the amount of methane by a combustion analysis with a volumetric gas-analysis ap-

PHYSIOLOGICAL RESPONSE TO VARIOUS CONCENTRATIONS OF SOME COMMON GASES AND VAPORS IN AIR[f]

Vapor or Gas	Kills Most Animals in a Very Short Time 1		Dangerous in 30 to 60 Minutes 2		Maximum Amount for 60 Minutes Without Serious Disturbances 3		Slight Symptons After Several Hours or Maximum Amount for Prolonged Exposure 4	
	Per Cent by Volume	Relative Order	Per Cent by Volume	Relative Order	Per Cent by Volume	Relative Order	Per Cent by Volume	Relative Order
Phosgene	0.02 – 0.05	1	0.0025	1	No Data	0	0.0001	1
Chlorine	0.10	2	0.004[a,b] – 0.006	2	0.0004	2	0.0001	1
Bromine	0.1	3	0.004 – 0.006	3	0.0004	3	0.0001	1
	0.06[b] – 0.10	4	0.05[a,b] – 0.07	6	0.02 –0.03	7	0.01[a] –0.015	7
Hydrogen Sulphide	0.1[a] – 0.20						0.02[b]	
	0.1[c] – 0.30							
Hydrocyanic Acid	0.048[b]	5	0.012[a,c] – 0.015	4	0.005 –0.006	4	0.002 –0.004	3
Hydrogen Chloride	0.1[a] – 0.2	6	0.15 – 0.2	7	0.005 –0.01	5	0.001 –0.005	4
	0.5[b]							
Sulphur Dioxide	0.2[b]	7	0.04 – 0.05	5	0.005[a] –0.02	6	0.01[b]	2[d]
							0.001[c]	
Carbon Monoxide	0.5[b] – 1	8	0.2 – 0.3	8	0.05[b] –0.10	9	0.05[a]	9
			0.2		0.05[a]		0.04[b]	
Ammonia	0.5 – 1	9	0.25 – 0.45	10	0.03[b]	8	0.01[a]	6
Benzene	1.9	10	No data		0.31 –0.47	11	0.15[c] –0.31	13
Gasoline	2.4	11	1.1 – 2.2	11	0.43 –0.71	14	No data	0
Methyl Bromide	0.2[e] – 4	12	0.2[e] – 0.4	9	0.1[e]	10	0.005[e] –0.017	5
Chloroform	6.8[a] – 8.2	13[d]	1.4	12	0.5 –0.6	13	0.2[b]	8
Carbon Tetrachloride	4.8 – 6.3	14	2.4 – 3.2	14	0.4 –0.6	12	0.16	11
Ethyl Bromide	10[e] –20	15	1[e] – 2	13	0.6[e]	15	0.17[e] –0.3	12
Methyl Chloride	15[e] –30	16	2[e] – 4	15	0.7[e]	16	0.05[e] –0.10	10
Ethyl Chloride	15[e] –30	17	6[e] –10	16	4[e]	17	2[e]	14
Carbon Dioxide	30[b]		6[b] –8		4[b] –6		2[b] –3	

[a] Bureau of Mines, *Technical Paper* **248** (1921).

[b] International Critical Tables, II (1927).

[c] Henderson Yandell and H. W. Haggard, "Noxious Gases," *A. C. S. Monograph* **35** (1927).

[d] Depending on value taken.

[e] Data from Figures 2, 3, 4 and 5, of *Public Health Bulletin* **185**. Where no reference number is given results are from references 1, 2 and 3.

[f] Table from Bureau of Mines, *R. I.* **3013**.

paratus. This is accomplished by taking a known amount of air sample, burning the methane in the presence of oxygen and calculating the percentage of the resultant methane from the contraction in volume produced by the combustion. In addition to these methods for detecting methane there is a more elaborate device known as a continuous methane recorder. This apparatus, when placed in an air current, will automatically determine and continuously record the amount of methane in the air.

Detection of Carbon Monoxide

The methods[5] that are generally used by the Bureau of Mines for detection of carbon monoxide in mine air are as follows:

(1) The use of small animals or birds; (2) the iodine pentoxide indicator; (3) the pyrotannic acid method for the quantitative determination of carbon monoxide in blood and air; (4) absorption or combustion analysis in one of several types of volumetric gas apparatus.

The first three methods are adapted for underground use, and the third and fourth are generally used in the laboratory. A device known as a continuous carbon monoxide recorder has been developed by the bureau. This device is designed largely for use in vehicular tunnels and will record on a time chart the carbon monoxide in parts per 10,000 and fractions thereof, being sensitive to about 0.20 per 10,000 (2 parts per million). The range of this apparatus is from 1 to 9 parts of carbon monoxide per 10,000 parts of air. A warning bell is arranged to ring when the carbon monoxide reaches a concentration of 2 parts per 10,000 or more.

Detection of Mine Gases Other than Methane and Carbon Monoxide

With few exceptions[5] mine gases other than methane and carbon monoxide can rarely be detected by any other means than chemical analysis. Carbon dioxide may occasionally be found in mines in sufficient quantities to be dangerous to the health and safety of miners. Generally, however, before this is possible a deficiency of oxygen will occur. Where there is a dangerous oxygen deficiency it can be detected by using a flame safety lamp, the flame of which will be extinguished when the oxygen is depleted to about 16 per cent.

As a rule, dangerous mine gases other than those named (methane, carbon monoxide, carbon dioxide and low oxygen) can be detected because they have a strong odor or are irritating to the eyes and respiratory passages. Such gases are rarely encountered in mine atmospheres in sufficient quantities to be dangerous, therefore means for detecting them other than by chemical analysis have not been developed.

Detection of Other Gases

Too much emphasis cannot be placed upon the necessity of definitely ascertaining the physiological nature of gases that may be encountered in an atmosphere whose composition is unknown. Without the proper protective equipment these atmospheres may prove fatal.

Before sewers can be entered without protective equipment, or repairs are made on storage tanks that have contained, or may contain, crude oil, gasoline or other distillates of petroleum, it is advisable to be sure that a minimum amount of vapor is present. The examination for vapor should be thorough; it should be made immediately before entry by any one, and periodically thereafter until the men have left the sewer.

The flame safety lamp has been suggested as suitable for this service and has been used to some extent. In response to inquiries, an investigation was made at the Pittsburgh Experiment Station to determine whether it is safe to use the miner's permissible-type flame safety[12] lamp in gasoline vapors and to ascertain their suitability in general for such use.

The investigation[13] revealed that while permissible miner's flame safety lamps, when correctly assembled and intact, will not ignite mixtures of gasoline vapor and air, these lamps are not suitable for determination of inflammable vapor content of the atmospheres in and around tanks. The lamps will give unmistakable evidence of the presence of an explosive mixture and will give satisfactory indications *to a trained observer* in vapor percentages of approximately half of the lower explosive limit, provided he can hold the lamp. Below this limit the lamps decrease in value as detectors and at 0.3 per cent and lower the evidence is so small and difficult to observe that it should not be depended upon.

Safe practice requires that workmen without respiratory equipment do not enter such places if any trace of gas is present, and since the tests show that the flame safety lamp cannot be depended on to give evidence of gas percentages below about 0.3 per cent (and not then except in the hands of one experienced in handling the lamp), it is manifest that the flame safety lamp is not suitable for testing for small percentages of these gases. The proper and efficient detection of petroleum vapors requires detectors that are more accurate and more readily observed than a flame safety lamp. Such detectors are advisable and at least three are used for this purpose, *viz.*, the U. C. C. industrial gas indicator, the Burrell Methane Indicator[14] and one recently developed by the Mine Safety Appliances Company. These apparatus are calibrated for various combustible gases.

If hydrogen sulphide or certain toxic gases are present, special tests for these must be provided. If hydrogen sulphide[15] is suspected, its presence can be ascertained by moistening filter papers with a 5 per cent, by weight, solution of lead acetate, and by introducing the paper into the place to

be sampled; the presence of hydrogen sulphide is indicated by a darkening of the paper. Should the filter paper be darkened after five minutes exposure, entry should not be made without the proper respiratory protection.[15]

There is an ever present danger of encountering explosive and poisonous gases in sewers, and tests to detect the presence of such gases should always be made before men are allowed to enter sewers or manholes. The tests should be made by competent men carefully trained in the use of the apparatus and should be made by *no one else*, because lives may depend upon the accuracy of the determinations.

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Industrial Wastes and Stream Pollution

The Effect of Precipitants on Textile Waste Liquors

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The textile industry creates large volumes of liquid wastes. In the early days of the industry, with decentralization of plants, these wastes were disposed of to the satisfaction of the plant management by pouring them back into the river from which the mill obtained its industrial water, or into an adjacent stream. The centralization of the textile industry in certain sections of the country, for example in the North Carolina Piedmont area, has intensified the practice of waste disposal by stream carriage in many localities to such a point that the streams are no longer able to dilute the ever-increasing volume to a point consistent with the conservation of wild life and the preservation of natural beauty. From the standpoint of the industry itself, the stream constitutes the most effective method of waste disposal, but, in the interests of health, conservation and public decency, state and federal regulatory bodies are becoming more and more insistent that the quality of water in a stream must not be seriously damaged by waste contamination.

Textile wastes vary widely in source and composition. They include spent dye liquors, kier liquors, soap baths and other miscellaneous wastes, together with their rinses, and are usually turbid, often highly colored, contain much suspended matter and frequently have a high biochemical oxygen demand.

Criteria of Purity for Discharge Into Streams

The factors to be considered in estimating the exact treatment to be given a waste before discharge into a stream are: (1) Use of stream; (2) dilution factor afforded; (3) biochemical oxygen demand; (4) acidity or alkalinity; (5) color; (6) odor; (7) suspended solids.

If the stream is to serve as a source of domestic water at some point below the point of addition of waste materials, it is obvious that the waste materials thus added must not be toxic or produce unpleasant physiological reactions in the concentration in which they will occur in the water supply. For industrial use, in many cases, water of high purity is demanded. This

demand may at times be difficult to fulfill if at some point upstream large amounts of industrial waste liquors are poured into the watercourse.

A waste which on thorough mixing with the waters of a stream does not materially alter the natural properties of that stream obviously requires no treatment, provided the amount of waste discharged is not materially increased. However, most wastes are discharged in amounts so large as to affect adversely the natural life of the stream. This is particularly noticeable where the waste is discharged intermittently in large doses, for under these conditions the contamination tends to persist in high localized concentration as the water flows downstream. A uniform distribution of waste and water is attained much more slowly with an intermittent discharge than with an equal amount of waste discharged continuously.

The organic matter in textile wastes is subject to oxidation, through the agency of bacteria, by the dissolved oxygen of the stream. The high oxygen demand of these wastes is destructive to animal and vegetable life, through the removal of dissolved oxygen.

Very acid or very alkaline waters are known to be harmful to aquatic life. It seems wise to require the discharge of an effluent as nearly neutral as possible, or at least of one which on dilution by the waters of the stream does not cause the water to vary much from the neutral condition.

The color of a waste may or may not be an index of the polluting power of the material. In many cases a small amount of an organic dye imparts a distinct color to water, but yet does not impair the chemical or biological quality of the water. In other cases a nearly colorless waste may, because of its high oxygen demand, acidity or alkalinity, be distinctly harmful. However, the color of an effluent seems one of the most important criteria in judging a textile waste, inasmuch as a colored stream, although it may not be harmful to aquatic life, is regarded as badly contaminated by the inhabitants of the region through which it flows. Further, the removal of color, by precipitation or coagulation, usually removes at the same time a large part of the suspended and dissolved organic matter, thus diminishing materially the biochemical oxygen demand. The odor is also usually eliminated or greatly reduced by this treatment.

While a water-white, neutral, clear effluent is desirable, it is recognized that this is, from a commercial standpoint, an unattainable goal. For the purpose of the investigation in hand it was decided that a color of 100 or less, based on the platinum-cobalt standards, would be regarded as satisfactory. This color is considerably less than that usually found in wastes treated in modern treatment plants, and is about equal in intensity to that of a very weak tea.

In view of the absence of evidence dealing with acceptable hydrogen-ion concentrations, it was decided that a slightly alkaline effluent, whose pH did not exceed 8.0, would be suitable. Inasmuch as few textile wastes

are acid, and these are usually small in volume, an acid effluent will rarely be discharged except as a result of deliberate acidification in treatment. Such acid wastes can readily be mixed with the alkaline residues to produce a neutral or slightly alkaline discharge. It is suggested that for acid wastes a minimum pH value of 6.0 be considered satisfactory for discharge into streams.

Experimental Work

Twenty-nine different textile wastes, obtained from the Proximity Manufacturing Company, the Proximity Print Works and the White Oak Mill of Greensboro, N. C., and from the Durham Hosiery Mills of Durham, N. C., have been studied. For each of the wastes coagulation tests were run with varying amounts of different reagents to determine the optimum amount of each reagent. The pH and the color were measured for each waste before and after treatment. The determination of color by comparison with the platinum-cobalt standards was at times a rather uncertain procedure because of differences in hue of the various treated liquors. Although the numerical value of the color is difficult to obtain accurately, its order of magnitude is readily determined, hence in this paper results are reported as either less than 100, or approximately 200, 300 or 500. Hydrogen-ion concentrations were obtained by colorimetric comparison with LaMotte pH standards. These determinations are subject to the same limitations as are the color measurements, the color of the liquor or treated waste tending to mask the indicator. Measurements of pH were fairly reproducible, and the data given here are considered accurate within 0.2 pH for treated liquors. The results on the raw liquors are probably less accurate, in most cases, due to the more intense color.

The reagents used included most of the less expensive bulk chemicals commonly used in chemical precipitation processes, in addition some less frequently used materials. The majority of the tests were conducted with alum, lime, copperas, calcium chloride, ferric chloride, sulphuric acid or mixtures of these reagents. Concentrated solutions of these materials were prepared, and the reagent under test was added in successively increasing amounts to a series of 200 cc. samples of the waste. The nature and rapidity of flocculation were observed and the mixtures were then allowed to stand 24 hours at room temperature, after which the ratio of sludge volume to supernatant liquid, and the color and pH of the supernatant liquor were determined. The amount of reagent necessary to reduce the color to 100 or less, or, if the color could not be reduced to 100 with a reasonable amount of reagent, the amount yielding the minimum color value for the series was recorded.

The results of these experiments are reported in Tables I, II, III and IV.

TABLE I

INDIGO WASTES

PROXIMITY MILLS, GREENSBORO, N. C.

(Color Less than 100 After Treatment Unless Otherwise Noted)

Source of Sample / Initial pH		Boil-out Box 7.8			Wash Box After Boil-out Box 8.0			Wash Box After Dye Vat 9.6			Soap Box 7.6			Wash Machine: Caustic Bath 7.4		
	Lb. per 1000 Gal.	Final pH	Sludge Volume: Supernatant Vol.	Lb. per 1000 Gal.	Final pH	Sludge Volume: Supernatant Vol.	Lb. per 1000 Gal.	Final pH	Sludge Volume: Supernatant Vol.	Lb. per 1000 Gal.	Final pH	Sludge Volume: Supernatant Vol.	Lb. per 1000 Gal.	Final pH	Sludge Volume: Supernatant Vol.
Copperas	249	6.8	1:1	25	7.8	1:10	U	..	..	U	..	..	U	..	..
Lime	U	..	..	9	11.9	1:20	28	11.1	1:20	U	..	..	9	11.9	1:10
Alum	249	5.4	4:1	25	7.3	1:4	U	..	..	33[1]	7.4	10:1	8	6.2	1:5
Calcium Chloride	33[2]	7.9	1:4	8	7.9	1:50	67[1]	7.5	1:50	25	7.5	1:1	U	..	..
Ferric Chloride	U	..	..	N	..	..	19	6.0	1:6	U	..	..	N	..	..
Copperas + Lime	C 42	..	..	C 17	..	..	C 17	..	..	C 17[2]	..	..	C 17	..	..
	L 22	8.3	1:3	L 5	8.2	1:10	L 19	7.9	1:20	L 28	8.0	10:1	L 5	7.6	1:10
Alum + Lime	U	..	..	N	..	..	A 17[1] L 19	8.0	1:50	..	7.8	10:1	A 8 L 5	8.1	1:50
Ferric Chloride + Lime	F 38[2] L 22	8.3	1:5	N	..	..	N	..	..	F 19[2] L 28	8.3	1:1	N	..	..

[1]—Color 200.
[2]—Color 300.
[3]—Color 500.
[4]—Color can be removed nearly completely from resultant filtrate by activated charcoal.
[5]—Addition of CO_2 assists separation, giving fairly satisfactory color removal.
[6]—Addition of lime gives good results.
[7]—This liquor clears with large amounts of strong acids: H_2SO_4, HNO_2 or HCl.

F—Ferric Chloride.
A—Alum.
C—Copperas.
L—Lime.
U—Results unsatisfactory
N—Reagent not tested.

For each dye the optimum amount of each reagent tested is given in pounds of reagent* per 1000 gallons of liquor. The pH values are given for the raw and treated liquors, and the ratio of sludge volume to supernatant liquor after 24-hour settling is recorded.

Indigo Wastes

The indigo wastes studied were obtained from the Proximity Manufacturing Company, the Proximity Print Works and the White Oak Mill of Greensboro, N. C. The boil-out waste is an alkaline, dark brown, turbid liquid resulting from the preliminary treatment of the fibre before dyeing. The wash water from this operation is light yellow and slightly turbid. The wash following the dye vat yields a dark blue, moderately turbid waste, while the discharge from the soap box (or softening bath) is a medium blue and very turbid. The indigo caustic wash produces a blue, slightly turbid liquor. The wastes from the boil-out box are small in volume in comparison to those obtained in the various later operations.

A study of Table I indicates that the joint use of copperas and lime produces the most satisfactory color removal. Alum alone appears to be the second choice, with the advantage that it produces an effluent of lower pH than the copperas-lime treatment. The requirement of high color removal imposed on this work necessitates the use of comparatively large amounts of chemicals. Manifestly for many situations an adequate clarification could be obtained with the use of smaller amounts of reagents than those given in the table.

Sulphur Wastes

Wastes from sulphur dyes are notoriously difficult to treat. Those studied in the present work include the waste and rinse waters from sulphur tumbler dyeing, liquor from sulphur jigs, wash from vacuum pan dyeing and waste from the sulphur machines of the Proximity group of mills, and sulphur black wastes from the Durham Hosiery Mills.

The most effective reagents for clarifying sulphur dye wastes seem to be strong acids, such as sulphuric, nitric or hydrochloric. By using a sufficiently large amount of acid, in some cases as much as 200 pounds of 60° Bé. sulphuric acid per 1000 gallons of waste, satisfactory color removal can be obtained. This treatment produces a highly acid, milky effluent. It would be objectionable to turn such an acid material directly into a stream, but by mixing with the alkaline liquors produced elsewhere in the mill this difficulty can be avoided and the treatment of the other wastes facilitated. Good clarification seems possible if large amounts of alum are

* Reagent amounts are based on the following formulas: Copperas, $FeSO_4 \cdot 7H_2O$. Calcium chloride, $CaCl_2 \cdot H_2O$. Lime, $Ca(OH)_2$. Alum, $Al_2(SO_4)_3 \cdot 18H_2O$. Ferric chloride, $FeCl_3 \cdot 6H_2O$. Sulphuric acid, 60° Bé.

TABLE II*

SULPHUR WASTES

Source of Sample Initial pH	Tumbler Liquor (Proximity) 7.8			Tumbler 1st Rinse (Proximity) 7.7			Tumbler 2nd Rinse (Proximity) 7.6			Jig Liquor (Proximity) 7.7			Machine Liquor (Proximity) 7.8			Vacuum Pan Dyeing: Continuous Wash (Proximity) 7.8			Black Waste (7) (Durham) ...		
	Lb. per 1000 Gal.	Final pH	Sludge Volume: Supernatant Vol.	Lb. per 1000 Gal.	Final pH	Sludge Volume: Supernatant Vol.	Lb. per 1000 Gal.	Final pH	Sludge Volume: Supernatant Vol.	Lb. per 1000 Gal.	Final pH	Sludge Volume: Supernatant Vol.	Lb. per 1000 Gal.	Final pH	Sludge Volume: Supernatant Vol.	Lb. per 1000 Gal.	Final pH	Sludge Volume: Supernatant Vol.	Lb. per 1000 Gal.	Final pH	Sludge Volume: Supernatant Vol.
Copperas	U	..	..	U	..	..	U	..	..	17[1]	6.8	6:1	U	..	..	17[1]	7.7	1:6	U	..	..
Lime	U	..	..	70[1]	12.6	1:20	42[1]	12.3	1:10	23	12.0	1:20	U	..	..	52	12.3	1:10	U	..	..
Alum	83[2]	7.0	1:1	33[2]	5.2	1:5	17	6.8	1:4	17	6.2	1:6	U	..	..	17	7.5	1:10	250[2]	..	4.1
Calcium Chloride	U[4,5]	..	..	U[5]	..	..	U	..	..	U[4]	..	..	U	..	..	U	..	..	N	..	..
Ferric Chloride	U	..	..	N	..	..	N	..	..	19	5.5	1:6	U	..	..	19	6.1	1:10	U	..	..
Copperas +							C 25			C 17[3]						C 17					
Lime	U	..	..	N	..	..	L 23	7.4	1:10	L 14	7.9	1:6	U	..	..	L 23	8.1	1:8	U	..	..
Alum +				A 33			A 12									A 8					
Lime	U[4]	..	..	L 23	7.8	1:20	L 23	8.1	1:20	U	..	..	U	..	..	L 23	8.1	1:20	N	..	..
Sulphuric Acid	200[1]	3.0	1:30	65	3.0	1:50	60	3.0	1:60	80	3.0	1:30	U[3,7]	..	..	N	..	..	U[7]	..	..

* For explanatory notes see Table I.

used, although no two sulphur wastes seem to require the same amount of treatment.

Rudolfs and Baumgartner[4] have studied a black sulphur waste from the Proximity Mills. This, from the similarity in treatment necessary to produce clarification, is the same type of waste as that reported in Table II as tumbler liquor. Rudolfs' figure of 86 pounds of alum per 1000 gallons of liquor is in agreement with that of 83 pounds reported above, while he recommends the use of somewhat smaller amounts of sulphuric acid than those indicated above. These experimenters did not report quantitative measurements of color, hence it is difficult to correlate their results with those given in the present paper. Rudolfs and Baumgartner concluded that ferric chloride in conjunction with hydrochloric acid, or copperas in conjunction with sulphuric acid produced the most satisfactory effluent. These resultant liquors are, however, milky in appearance and the color would seem to be well above that demanded in the present work.

At present it does not seem economically feasible to lower the color of concentrated sulphur dye wastes to a value of 100. This can, however, be readily accomplished for the wash waters following the dyeing operations, a wide choice of reagents being available as shown in Table II. Since sulphur dye wastes rarely constitute the entire effluent of a plant and since but part of these sulphur wastes are concentrated, it seems wise to plan treatment as though these particular wastes were all dilute, and accept the darker colored liquid thus produced. Complete clarification can be accomplished only at unwarranted expense. Further work on this subject, particularly as affected by variations in the dyeing process and in the dye bath, is badly needed.

Processing Wastes

Under the heading of processing wastes have been grouped the effluents produced in such operations as kiering, sizing, de-sizing, bleaching and degumming. The materials studied include kier liquor, kier wash, slasher (size box) waste, desize bath and desize wash from the Proximity group of mills, and peroxide bleach and silk degum and dye liquor from the Durham Hosiery Mills.

From the data of Table III it appears that the use of copperas in conjunction with lime offers the greatest probability of successful treatment. Using large amounts of chemicals, kier liquor can be cleared by this procedure, although such a process would be prohibitively expensive. Copson and Curtis,[2] after a study of various methods for the disposal of kier liquor, developed a process which combined carbonation by stack gas with precipitation by calcium chloride. This process removes about 75% of the color of the liquor. From our investigation, it would seem that kier liquor given this treatment is, at the end, too high in organic matter and color

TABLE III*

PROCESSING WASTES

(Color After Treatment Less than 100 Unless Otherwise Noted)

Source of Sample	Kier Liquor (Proximity)			Kier Wash (Proximity)			Slasher Waste (Size Box) (Proximity)			De-size Bath (Small Singer) (Proximity)			De-size Wash Small Machine (Proximity)			Silk De-gum and Dye (Durham)			Peroxide Bleach (Durham)		
Initial pH	9.8			7.9			3.8			4.0			6.0			7.6			7.8		
	Lb. per 1000 Gal.	Final pH	Sludge Volume: Supernatant Vol.	Lb. per 1000 Gal.	Final pH	Sludge Volume: Supernatant Vol.	Lb. per 1000 Gal.	Final pH	Sludge Volume: Supernatant Vol.	Lb. per 1000 Gal.	Final pH	Sludge Volume: Supernatant Vol.	Lb. per 1000 Gal.	Final pH	Sludge Volume: Supernatant Vol.	Lb. per 1000 Gal.	Final pH	Sludge Volume: Supernatant Vol.	Lb. per 1000 Gal.	Final pH	Sludge Volume: Supernatant Vol.
Copperas	U	..	..	17[3]	7.8	1:10	N	..	..	N	..	..	U	..	..	U	..	..	U	..	..
Lime	U	..	..	9	11.9	1:20	14	8.4	1:10	N	..	..	..	8.2	1:10	U	..	..	28	10.1	1:2
Alum	U	..	..	17	7.4	1:50	N	..	..	N	..	..	U	..	..	33[1]	4.4	1:10	U	..	..
Calcium Chloride	U	..	..	8	7.8	1:50	N	..	..	N	..	..	U	..	..	N	..	..	17	7.8	1:2
Ferric Chloride	U	..	..	U	..	..	N	..	..	N	..	..	N	..	..	N	..	..	U	..	..
Copperas +	C100[3]			C 8						C 25[1]			C 4			C 50			C 17		
Lime	L 94	8.3	1:1	L 5	7.9	1:10	N	..	..	L 14	7.9	1:6	L 37	8.0	1:20	L 48	7.9	1:4	L 23	7.9	1:5
Alum +										A 33[1]			A 4			A 17			A 17		
Lime	U	..	..	N	..	..	N	..	..	L 14	7.9	1:8	L 37	7.8	1:20	L 41	7.9	1:6	L 28	7.9	1:5
Ferric Chloride +	F 113[3]			F 19															F 19		
Lime	L 94	8.2	1:1	L 9	8.3	1:15	N	..	..	N	..	..	N	..	..	N	..	..	L 23	7.9	1:4

* For explanatory notes see Table I.

to be considered a satisfactory effluent. This procedure seems to offer an inexpensive method of partial clarification, but it is not considered to be a complete solution of the problem. In this connection it might be noted that a combination of carbonation with calcium chloride treatment offers possibilities in the treatment of wastes from other textile operations. A partial series of experiments has shown that this process can be made to clarify the indigo wastes completely, and that it decolorizes certain sulphur wastes successfully, but fails with others.

Miscellaneous Dye Wastes

In Table IV are reported results obtained with miscellaneous wastes. These include the wash water following aniline black dyeing, the wastes from color printing (a variable, highly colored mixture), and a sample from the lagoon outfall (one of the main plant waste outlets, containing a variety of different wastes in variable proportions) from the Proximity Mills. The Durham Hosiery Mills kindly supplied samples of a direct silk dye bath; two different rayon direct dye baths; the diazotization, developing, and black waste in developed black dyeing; and a direct cotton bath.

In this group the most satisfactory reagents from a standpiont of color removal appear to be copperas and lime, or ferric chloride and lime.

Mutual Precipitation of Dye Wastes

Although there is some tendency for a dye waste to coagulate when mixed with a waste from a different operation, this does not seem to be sufficiently pronounced to permit of much reduction in the chemical dosage necessary for good color removal. A mixture of dye wastes seems to require about the same total amount of reagent as would the liquors if handled individually. This is in part due to the fact that the liquors are largely alkaline. If large amounts of acid wastes were available, the neutralization of the alkaline wastes by the acid wastes would undoubtedly produce a certain amount of mutual precipitation with a consequent lowering of the required chemical dosage.

A mixture of equal parts of fourteen wastes (five indigo wastes, kier wash, five sulphur wastes, de-size bath, de-size wash and aniline black wash) was prepared and treatment calculated on the basis of the individual data recorded in Tables I–IV. On testing, the calculated reagent quantity gave satisfactory results while amounts somewhat smaller gave incomplete color removal. This was further checked by treating mixtures of kier liquor and various other wastes to determine the optimum amount of precipitant. The quantities thus determined corresponded satisfactorily with the amounts that would be predicted if the wastes had been treated separately.

TABLE IV*

MISCELLANEOUS DYE WASTES

Source of Sample Initial pH	Aniline Black Wash Machine (Proximity) 6.6			Color Shop Waste (Proximity)			Silk Direct Dyeing (Durham) 7.6			Rayon Direct Dyeing Sample A (Durham) 7.7			Rayon Direct Dyeing Sample B (Durham) 7.7		
	Lb. per 1000 Gal.	Final pH	Sludge Volume: Supernatant Vol.	Lb. per 1000 Gal.	Final pH	Sludge Volume: Supernatant Vol.	Lb. per 1000 Gal.	Final pH	Sludge Volume: Supernatant Vol.	Lb. per 1000 Gal.	Final pH	Sludge Volume: Supernatant Vol.	Lb. per 1000 Gal.	Final pH	Sludge Volume: Supernatant Vol.
Copperas	U	..	..	U	..	..	U	..	..	U	..	..	33	5.4	1:20
Lime	9	11.8	..	23	11.8	..	47	11.2	1:10	U	..	..	47	11.3	1:6
Alum	8	4.0	1:8	U	..	..	U	..	..	U	..	..	17	4.0	1:20
Calcium Chloride	U	..	..	U	..	..	N	..	..	U	..	..	8	6.8	1:20
Ferric Chloride	N	..	..	N	..	..	U	..	..	U	..	..	N	..	..
Copperas +	C 17	..	..	C 17[2]	..	..	C 58[1]	..	..	C 33	..	..	..	..	..
Lime	L 5	8.0	1:8	L 37	8.0	1:4	L 37	8.0	1:6	L 37	8.0	1:5	N	..	..
Alum +	A 8	..	..	A 17[2]	..	..	A 33[2]	..	..	..	..	..	A 8	..	..
Lime	L 5	7.9	1:8	L 14	8.3	1:6	L 37	8.0	1:6	U	..	..	L 37	8.1	1:20
Ferric Chloride +	..	..	..	F 19[1]	..	..	F 49	..	..	F 38	..	..	..	..	..
Lime	N	..	..	L 47	8.3	1:4	L 23	8.3	1:10	L 37	8.3	1:10	N	..	..

Source of Sample Initial pH	Developed Black Waste (Durham) ...			Developed Black (Developing) Waste (Durham) 8.0			Developed Black (Diazotization Waste) (Durham) 3.0			Direct Cotton Waste (Durham) 7.4			Lagoon Outfall (Mixed Wastes) (Proximity) 7.7		
	Lb. per 1000 Gal.	Final pH	Sludge Volume: Supernatant Vol.	Lb. per 1000 Gal.	Final pH	Sludge Volume: Supernatant Vol.	Lb. per 1000 Gal.	Final pH	Sludge Volume: Supernatant Vol.	Lb. per 1000 Gal.	Final pH	Sludge Volume: Supernatant Vol.	Lb. per 1000 Gal.	Final pH	Sludge Volume: Supernatant Vol.
Copperas	U	..	..	U	..	..	N	..	..	U	..	..	8[1]	7.6	1:10
Lime	U	..	..	U	..	..	37	7.9	1:20	37	10.8	1:10	14	10.8	1:50
Alum	U	..	..	U	..	..	N	..	..	17	4.1	1:50	8[1]	7.5	1:10
Calcium Chloride	N	..	..	U	..	..	N	..	..	8[1]	6.8	1:50	U	..	..
Ferric chloride	U	..	..	U	..	..	N	..	..	N	..	..	N	..	..
Copperas +	C 50[3]	..	..	C 38	..	..	..	..	..	C 17	..	..	C 17	..	..
Lime	L 47	7.9	1:2	L 28	7.9	1:6	N	..	..	L 23	8.2	1:10	L 9	7.7	1:10
Alum +	..	..	..	..	..	..	..	..	..	A 8	..	..	A 8	..	..
Lime	U	..	..	U	..	..	N	..	..	L 37	8.1	1:20	L 9	7.9	1:10
Ferric Chloride +	F38[1]	..	..	F 38[1]	..	..	..	..	..	..	..	..	F 4	..	..
Lime	L 47	8.3	1:5	L 37	8.3	1:5	N	..	..	N	..	..	L 5	8.0	1:10

* For explanatory notes see Table I.

In general it seems that the reagents copperas and lime together form the most satisfactory treating material from a standpoint of color removal. Nearly all the wastes studied are decolorized and precipitated by this mixture. The precipitate formed varies in consistency and speed of settling with the ratio of copperas to lime used. In general copperas produces a relatively slow-settling gelatinous sludge, while lime yields a granular free-settling precipitate. The ratio of sludge volume to volume of supernatant liquid after 24-hour settling seems to be an index of the settling speed of the slurry.

Wise[6] recommends the use of the reagents ferrous sulphate and lime, although in quantities less than those indicated in Tables I–IV. He reports that two treatment plants, handling miscellaneous rayon, cotton and silk finishing wastes, are in successful operation using these materials. Snell and Bruce[5] find these reagents satisfactory in treating silk wastes. Besselievre and Anable[1] recommend the use of alum, ferrous sulphate and lime in a continuous-flow system, while Hadley[3] suggests the use of alum and lime, with sulphuric acid where necessary to neutralize excessively high alkalinity.

Each textile waste presents its own distinct disposal problem. Often a composite effluent can be satisfactorily treated only after a study of each of the wastes in the mixture. It is hoped that the data presented in Tables I–IV may be of assistance to those engaged in planning a treatment process. The amounts of chemicals there specified are maximum values. In many cases color removal, although not complete, can be adequately accomplished with the use of much smaller amounts of material than there indicated. In any case of treatment of separate or combined wastes or their discharge into a sewer tributary to a sewage treatment plant it appears necessary to provide twin holding tanks, probably of 24-hour capacity, so that the required chemical dosage for the batch may be determined and the treatment applied uniformly, or the discharge into a sewer regulated to a constant rate throughout the day.

The authors are indebted to the Chemical Foundation for financial assistance in the form of a research grant which made this study possible, and to the managements of the Proximity Mills of Greensboro, N. C., and of the Durham Hosiery Mills of Durham, N. C., for their kind cooperation in providing samples.

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Effect of Sunlight on Dissolved Oxygen in White River

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The concentration of dissolved oxygen has been used as an indication of the extent of pollution in surface water and its capacity to absorb pollution. This determination has been used so long and so widely that it is the first information wanted when a pollution problem is under consideration.

It is recognized that the amount of oxygen dissolved in a stream is governed by the relation between the amount of polluting matter and the volume of the receiving body of water, as well as the concentration and ease of putrescibility of the organic matter. Temperature enters into the consideration since at an elevated temperature the oxygen content may be depleted while at a lower temperature the reaction may go on so slowly that re-aeration is able to maintain a substantial oxygen concentration. In connection with water purification work it has been known for a long time that the growth of algae affects the dissolved oxygen content, producing at times more than 300 per cent saturation.

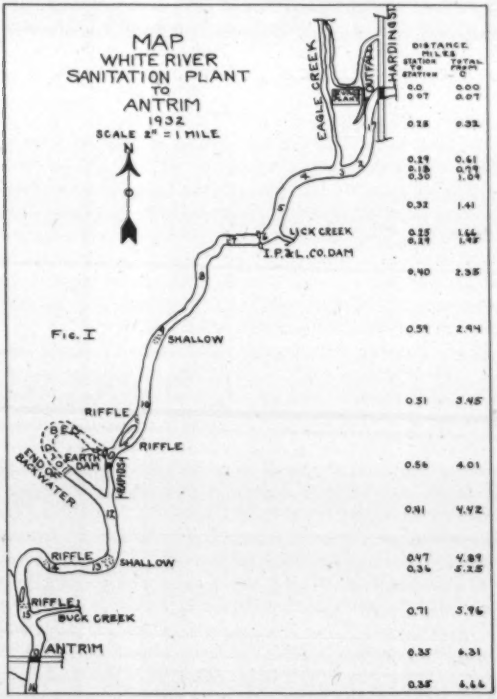
Although the measure of the oxygen dissolved in a polluted stream is of very great value in determining the condition of the water and the extent of pollution, yet it must be used with care and with full knowledge of the conditions under which the samples are taken.

It is possible to encounter a dilution factor such that the water receiving mid-day sewage is devoid of oxygen, while that receiving night sewage may contain a fairly satisfactory amount. Under such conditions, samples from the stream below the point at which pollution enters may be timed to show moderate or excessive pollution and fail to disclose the true condition. It is possible to encounter a relation between the diluting water and pollution such that in cloudy weather a very grave condition may be indicated while during bright weather the pollution may appear to be slight or nominal. It is possible, also, to obtain samples which are very different in oxygen content taken from one side of the stream in sunlight and from the opposite side in dense shade, and to take samples at different times of day at the same point and with similar quantities of pollution, finding, during daylight, considerable oxygen concentrations and, during the night and very early morning, zero oxygen dissolved figures.

The accompanying tabulations report work done during the summer of 1932 on White River below the Indianapolis Sewage Plant outfall. Figure 1 shows the location of 15 sampling points between the sewage plant outfall and the first bridge, which is located at Antrim. The distances be-

tween sampling points from the outfall are shown. Between the noted riffles and shallows are rather deep pools.

In Table I three groups of figures are shown on five sampling stations. Sample 12 is approximately 4.35 miles below the sewer outfall and during these observations was approximately 23 hours in time of flow. Sample 13 is 4.8 miles and sample 14 is 5.35 miles down-stream. The time of flow



from station to station was approximately 2 hours. Sample 12A was taken about 150-ft. up-stream from sample 12 and just below a very extensive riffle. It was taken in rather rapidly moving deep water, in the shade, to show the effect of riffle alone. The sample labeled "Old Bed" was taken in a pool which was formerly the main river channel, now cut off at the up-stream end. This pool is affected to some extent by the sewage which

TABLE I

DAILY VARIATION IN DISSOLVED OXYGEN, WHITE RIVER, 1932

Date	Sec. Ft.	Temp., °C.	12A			12			13			14			Old Bed		
			Time	D. O.	Cl	Time	D. O.	Cl	Time	D. O.	Cl	Time	D. O.	Cl	Time	D. O.	Cl
8/24	140	27				6:45A	0	71	6:50A	0	70	6:56A	0	69	7:16A	0.6	34
						7:30A	0	74	7:37	0	69	7:43	0	70	8:02	1.0	34
						8:15	0	74	8:22	0.4	69	8:27	0.5	69			
									8:47	0.4	69	8:59	0.9	69			
						2:30P	0	87	2:37P	1.8	79	2:45P	3.2	76			
9/11	216	24.5				7:25A	0	61	7:11A	0	58	7:18A	0	56			
						8:12	0	60	8:18	0	59	8:25	0.2	56	7:44A	1.9	40
						8:57	0	60	9:04	0	60	9:10	0.3	59	8:54	1.9	37
			9:36A	1	59	9:39	0.5	60	9:45	0.2	60	9:52	0.9	59	9:30	2.3	..
9/13	190	25	6:27A	0	54	6:35A	0	53	6:41A	0	50	6:55A	0	44	6:37A	6.4	34
			7:49	0	57	7:49	0	56	7:55	0	50	8:01	0.6	49	7:41	6.0	33
			8:39	0	58	8:42	0	57	8:43	0.4	52	8:53	1.0	52	8:35	5.2	34
			9:38	0.3	61	9:41	0.1	59	9:47	0.25	53	9:53	1.6	52	9:33	7.4	33
			10:37	0.5	64	10:38	0.1	62	10:45	0.1	56	10:50	1.0	54	10:31	7.5	32
			11:37	0.7	63	11:40	0.1	62	11:45	0.4	57	11:50	2.2	54	11:33	8.0	31
						3:32P	1.8	64	3:41P	1.8	62	3:47P	2.6	63	3:31P	8.6	39

may be forced into it by change in river elevation, but is fed for the most part by springs and land drains. Very little water flows into it. During the summer months it is green with free floating plankton.

The samples were collected from a motor boat and this particular stretch of river chosen for observation because the depth is sufficient to allow a motor boat to travel up-stream and particularly because the flow is from east to west for much of the distance between sampling points 12 and 14, thus exposing the water to sun throughout the entire day. Just down-stream from sampling point 13 there is a rather shallow stretch of water in which water grass grows luxuriantly, affording a breeding ground for some of the algae forms.

Chloride is shown for each sample and its concentration is taken as an indication of organic matter in the stream. The samples collected on the same day should be considered as a group rather than comparing samples from day to day, since the dilution is not entirely uniform.

Part of the Old Bed is in shade during the greater part of the day but at least half of it is in bright sun after 8:30 A.M. On all three days there was an increase in the oxygen content with the exception of September 13 when there was a reduction until 8:30 A.M. After this time there was a very rapid increase. Figures are not available for the night hours but it is assumed that the oxygen developed during the day suffers reduction through the decomposition of the dead algae cells until the sunlight is effective again. The low chloride figures obtained at this sampling point indicate a relatively small amount of pollution and, through the summer, carp were observed continually in this pool, even when the river itself contained zero oxygen.

Sample 12 on August 24 carried a considerable organic load, as shown by the chloride figures, and contained no dissolved oxygen. Samples 13 and 14, with a similar organic concentration and with, at most, only four hours more time, reached 0.9 p. p. m. of oxygen by 9 A.M. and by mid-afternoon contained 3.2 p. p. m. of oxygen. At 7 A.M. the stretch of river between sampling points 13 and 14 was at least 60 per cent in sunlight and practically all of it was in bright sun until after the last samples were taken. It is probable, from the chloride figures, that sample 12 contained rather strong sewage in the afternoon, so that even the riffle above it and the sunshine during the middle of the day could not keep up with the demand for oxygen and it is also quite possible that the high organic content made the water too toxic for algae to grow in it extensively. The water leaving sampling point 14 with 0.5 p. p. m. oxygen arrived at Antrim at 12:30 P.M., having traveled a distance of about 1 mile, one-half of the distance over a riffle, with an oxygen content of 3.6 p. p. m.; and that leaving sampling point 14 at 2:45 P.M. with an oxygen content of 3.2 p. p. m. arrived at Antrim with an oxygen content of 5 p. p. m. After this time,

with shadows falling over most of the stream between these two points, the oxygen content at Antrim fell gradually, reaching zero at 9 P.M. This water left sampling point 14 at about 5 P.M. in sunlight and traveled over the riffle mentioned above where algae growth was plentiful and where re-aeration could come into play. Yet the oxygen demand of the water was such that, without the intervention of photosynthesis, the supply already dissolved was exhausted within a period of perhaps two hours after leaving the riffle and entering the pool above Antrim.

On September 11, relatively the same thing is shown as on August 24, except that the sampling was extended more than an hour later in the morning, at which time oxygen was obtained at sampling point 12. It is interesting to note that a sample taken at 12 contained 0.5 p. p. m. of oxygen, while that at 12A, almost immediately above it, contained twice the amount, showing the effect of the riffle above. On this day, on the basis of chloride determinations, the water passing all four sampling points was practically identical in organic content. The last sample taken at sampling point 14 passed sampling point 12 before the work of the day began, but it passed sampling point 13 shortly before the second sample of the day was collected and contained no oxygen at that time. This is a case in which the oxygen increased from zero to 0.9 p. p. m. in the course of 2 hours flow through a distance of about 0.5 mile in the bright sunlight.

On September 13 the same general relationship existed between the samples taken at the various points for the various hours. On this date a number of samples were taken at sampling point 12A, in the shade, immediately below a riffle and just above sampling point 12. This riffle is rather extensive and shallow and there are extensive algae growths on the stones. While the chloride figures were somewhat lower than those obtained September 11 the concentration of organic matter was such that even re-aeration over the riffle during the night was insufficient to meet the oxygen demand of the water, and it was not until mid-morning that oxygen was found in the sample taken at this point. It increased from that time on. The oxygen at sampling point 12 was zero until it appeared at 12A but was only 0.1 p. p. m. throughout the morning, which shows that, up to this time, photosynthesis plus re-aeration over a riffle was insufficient to supply the water with more oxygen than its own demand required. From the chloride figures it is plain that water passing sampling point 12 during the latter part of the morning contained more organic matter than that passing the other points, but that passing 12 at the start of the observations for the day arrived at 13 and 14 before noon so that the comparison from station to station is as accurate as for the previous days. Even with the increased organic content, as shown by the samples taken during the afternoon at all three points, photosynthesis has increased the oxygen at station 14 from zero to 2.6 p. p. m.

TABLE II

MORNING AND AFTERNOON DISSOLVED OXYGEN IN WHITE RIVER, SUMMER 1932

Time of Starting Trip*	8–22 Monday—Fair		8–23 Tuesday—Fair		8–24 Wednesday—Fair		9–13 Tuesday—Fair		9–26 Monday—Cloudy and Rain	
	A.M. 8:00	P.M. 1:50	A.M. 8:10	P.M. 2:00	A.M. 5:30	P.M. 1:15	A.M. 5:10	P.M. 2:90	A.M. 8:53	P.M. 2·05
Sample										
1	5.6	7.0	4.8	3.6	3.4	2.6	5.2	5.8	3.4	3.6
2	4.4	4.4	0.8	0	0	0.6	1.6	2.0	3.8	3.4
3	4.0	1.6	0	1.2	0	1	0	0.4	3.2	3.2
4	3.2	5.6	0	3.8	0	1.8	0	2.4	2.8	2.4
5	2.6	4.8	0	5.4	0	0	0	2.6	2.2	1.8
6	3.4	6.0	0	4.6	0	0	0	3.2	2.0	1.8
7	3.8		0	2.8	0	0	0	4.2	4.6	3.2
8	3.8	5.0	0	2.0	0	0	0	3.6	3.6	2.8
9	1.8	6.4	0	2.2	0	0	0	3.0	3.8	2.8
10	1.0	7.2	0	3.4	0	0	0	2.0	3.8	3.0
11	2.2	7.2	0	2.0	0	0	0	2.2	3.8	3.0
12	2.0	6.4	0	1.8	0	0	0	1.8	3.4	3.0
13	1.8	7.4	1.0	2.8	0	1.8	0	1.8	3.0	3.4
14	2.4	7.4	1.8	3.6	0	3.2	0	2.6	2.6	3.2
15	2.8	5.8	2.2	4.0		4.2		2.2	2.8	4.0
Antrim	2.0							4.8	2.7	3.8

* Samples taken in numerical order, that at Antrim being taken about 1.5 hrs. after starting trip.

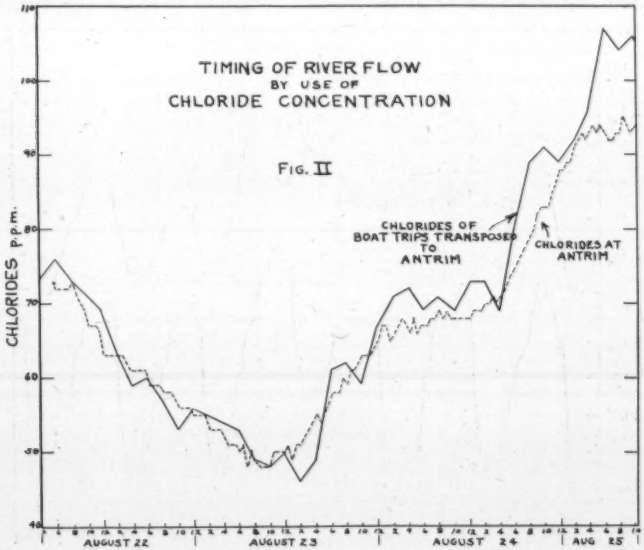
TABLE III

MORNING AND AFTERNOON CHLORIDES IN WHITE RIVER

Sample	8–22		8–23		8–24		9–13		9–26	
	A.M.	P.M.	A.M.	P.M.	A.M.	P.M.	A.M.	P.M.	A.M.	P.M.
1	41	52	51	111	104	95	70	60	46	51
2	44	67	82	122	107	90	58	83	34	53
3	52	69	78	101	109	94	65	72	32	50
4	49	47	66	73	107	88	66	50	31	48
5	51	41	72	67	113	95	67	50	31	42
6	54	49	68	72	97	104	66	57	36	34
7	54	46	73	72	97	102	67	55	34	37
8	54	47	72	70	95	102	67	57	36	36
9	55	52	70	70	95	102	65	61	34	33
10	59	54	65	71	79	98	59	63	33	32
11	59	56	60	70	76	91	55	64	34	32
12A							54			
12	61	58	59	65	71	87	53	64	34	32
13	62	59	52	61	70	79	50	62	35	33
14	62	58	51	59	69	76	44	63	36	33
15	63	59	49	55		73		59	36	33
Antrim	68							59	35	34

Tables II and III show the dissolved oxygen and chlorides in samples taken by boat between the sewage plant outfall and Antrim in the morning and afternoon on each of five days. August 22 and September 26 fell

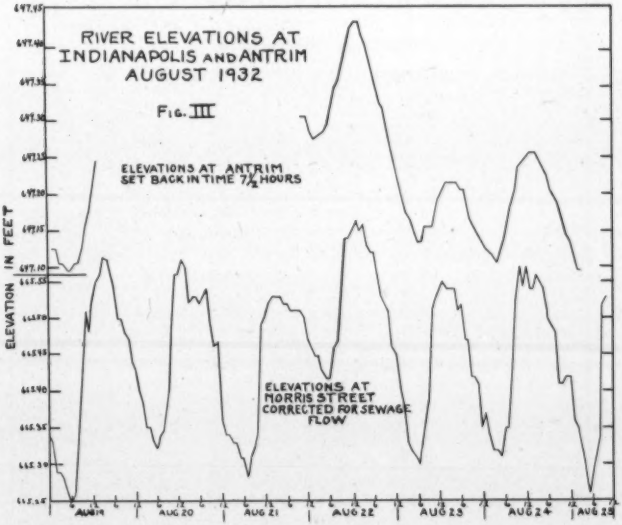
on Monday. In both cases the morning samples show some oxygen on account of the fact that Saturday afternoon and Sunday sewage is weaker and of less volume. The relatively low chlorides on these days is evidence of a lower concentration of organic matter in the stream. The 22nd was fair and the oxygen in the afternoon samples shows a decided increase over those taken in the morning. September 26 was a cloudy day, with rain, and the samples in the afternoon contained a lower oxygen content, due to the increased time in contact with the organic matter in the sewage.



August 23 and September 13 were Tuesdays. In both cases, oxygen is absent for most of the samples in the morning but being bright days a very material amount of oxygen is found in the afternoon samples. August 24 was fair. As was expected, the morning samples contained no oxygen but the afternoon samples likewise contained none for the distance traveled. An examination of the chloride figures for this day indicate that the concentration of organic matter must have been materially higher than on the other days under discussion, so that the oxygen-produced by photosynthesis could not keep up with the demand of the organic matter, or the water may have been so toxic and turbid that algae could not grow. The oxygen

that appears in the afternoon of this date below sample 13 is in water with less chloride content than is found in the upper part of the stream.

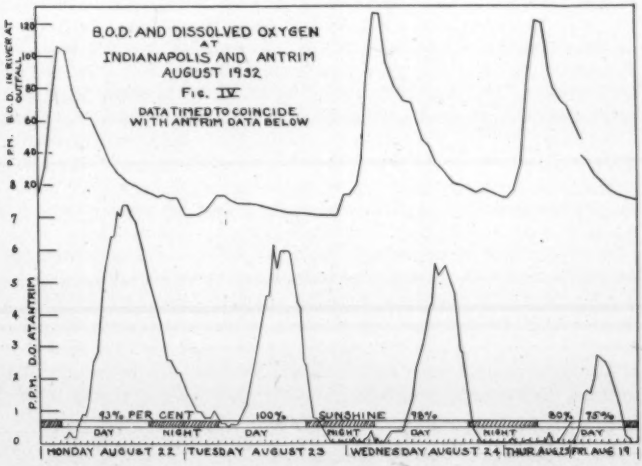
The samples taken at Antrim are of considerable importance since this is the first bridge over the stream below the sewage treatment plant. When the sampling trip is made by automobile, the Antrim sample is collected between 11 and 12 o'clock in the morning. It is plain that, with proper concentration of pollutional material and under certain weather conditions, the sample taken at this point may appear very much better than the true average conditions.



During the period August 19 to August 25, 1932, a number of samples were taken at Antrim on half-hour intervals to learn the condition there throughout the entire 24-hour day. On the samples collected, dissolved oxygen, free ammonia and chloride were determined. The elevation of the water in the river was read hourly. The free ammonia figures were discarded since the variation was slight and the information given by them not correlated with other observations. During this period a number of trips were made by boat between the Sanitation Plant and Antrim. Figure 2 was made by matching the chloride figures obtained on samples collected at the various sampling points with those obtained on the samples

taken at Antrim. In this way the time of flow between certain points and Antrim was obtained. The flow from the Sanitation Plant to Antrim under the conditions existing at that time was found to require about 31.5 hours, and the time between sampling points to be, quite uniformly, about 2 hours.

By plotting the elevation of the river below the sewage outfall and comparing with the elevation of the water at Antrim, it was found that the time elapsing between peaks at the two points was about 7.5 hours. (Figure 3.) As water flows over a riffle and into a pool the level of the entire pool is increased almost instantly. Just what time lag occurs in the pool is not known, but is very short and the conclusion seems justified that the time



of flow over riffles between the Sanitation Plant and Antrim amounts to the time difference in peaks of 7.5 hours. Some of the riffles are quite shallow and some are much deeper but, in any case, the water must be flowing in a rather thin layer for a total of the time noted above in the stretch of river between the Sanitation Plant and Antrim.

The dissolved oxygen at half-hour intervals is shown in Figure 4 for the period Monday, August 22, through Thursday, August 25, with Friday, August 19, shown at the end of the graph, although chronologically it should have been shown first. On this same graph is noted, daily, the per cent of sunlight, and day and night are indicated on the basis of the time of sunrise and sunset.

It is known that the organic load in the plant effluent increases through the week, partially on account of stronger sewage but largely on account of the gradual slowing down of the activated-sludge process, apparently on account of exhaustion of sludge, which usually recovers over the week-end. This is referred to in "The Hourly Variation of Indianapolis Sewage" (SEWAGE WORKS JOURNAL, **4,** 815 (1932)). In line with that report is the gradual reduction in oxygen peak for the days shown in Figure 4.

It will be noted that the dissolved oxygen peak at Antrim comes shortly after noon and the low point is reached after nightfall, some time apparently being required for the organic matter in the river to use up the oxygen supply. On the upper part of the same figure is shown the hourly B. O. D. load in the river. This is calculated on the basis of the B. O. D. as determined in the composite of 24 hourly samples of plant effluent for the day, and distributed to the hours on the basis of the average hourly variation in sewage concentration. This curve is made to coincide in point of time with the data at Antrim. The peak load leaving the plant in no case corresponds with the peak oxygen at Antrim. With time of flow other than 24 hours between the two points, the strong sewage leaving the Sanitation Plant could not reach Antrim at the time the peak oxygen is noted. It might be said that the peak oxygen at Antrim comes as a result of the passing of the peak load. This, however, cannot be a factor since the Sunday sewage passing Antrim does not interfere with the timing of the peak oxygen and for an average day the minimum organic load passes Antrim *with* the minimum oxygen content. If it were a matter entirely, or even largely, of organic concentration, the *peak* oxygen at Antrim would coincide with the *minimum* organic load. Obviously the oxygen peaks noted are caused by photosynthesis, for the most part, with the concentration of putrescible organic matter as a factor, not only in using up the oxygen produced and available, but in inhibiting algae growth by the formation of toxic materials when the concentration is extremely high.

Conclusion

1. The organic load in White River below Indianapolis is frequently such that, in bright sunlight, the biologic activity of the river is able to maintain a considerable oxygen concentration, but in the absence of sunlight the oxygen content may be zero.

Discussion of Paper in Sewage Works Journal, January, 1933, by Earle B. Phelps and Clarence J. Velz on "The Pollution of New York Harbor"

BY RICHARD H. GOULD

Engineer, Sewage Disposal and Intercepting Sewers, Department of Sanitation, New York City.

The paper by Phelps and Velz on "The Pollution of New York Harbor" is of outstanding importance. The studies and long experience of the senior author on this particular problem are such as to lend great weight to the conclusions that are reached. The problem is an extremely complicated one. In working out any quantitative solution such as presented by Phelps and Velz a number of assumptions must be made and before full reliance can be placed in the accuracy of the results it seems wise to compare the assumptions with the theory as we understand it and the conditions that actually exist.

The assumption is made, based on observations of Professor Mitchell made in 1886, that there is a net flow of sea water from Long Island Sound through the harbor and out to sea past the Narrows in the amount of about 10,000 cubic feet per second. The accuracy of this assumption is open to grave question. The importance of this assumption will be seen when it is recalled that the estimated mean summer runoff of land water at the Narrows from the Hudson and Passaic Rivers is about 17,000 c. f. s.

In 1914 the Coast and Geodetic Survey and the Metropolitan Sewage Commission were not convinced that there was a substantial net flow through the harbor from the Sound, although computations by the Commission's engineers indicated a net flow approximately as stated by Professor Mitchell. The theory on which this computation was based was that water surface elevations taken at Sandy Hook and at Throgg's Neck on the Sound were such that the maximum slope of the water surface northward to the Sound was exactly equal to the maximum slope southward to the ocean, but that the actual average elevation of the water surface on the southward slope was 1.4 ft. higher than on the northward slope. The conclusion was that as the slopes were identical and that during the southward flow the depth was 1.4 ft. greater with a correspondingly greater area of cross-section and hydraulic radius, that the flow southward must be greater. The net flow was computed in the approximate amount stated which was about 5 per cent of the total flows involved.

In this computation, so far as is known, no consideration was given to the fact that the water at Throgg's Neck and the ocean water at Sandy Hook did not have the same specific gravity. The percentage of sea water

at Throgg's Neck may be from 10 to 20 per cent less than at Sandy Hook. The actual hydraulic slope northward would therefore be greater than would be apparent from the elevations of the water surfaces and similarly the southward slope would be less than assumed. It is also true that the stream flows of the Hudson and Passaic Rivers are added to the tidal flows about half-way between Throgg's Neck and Sandy Hook. These flows pass out from the Narrows only on the ebb flows and have the effect of making the southerly flows over part of the distance greater than the northerly flows. The effect of both of these two considerations of specific gravity and land water flow is to reduce the computed figures for a net southerly flow of sea water from the Sound. These effects are of a magnitude enough to approximately account for the computed differential flow or at least to reduce the quantities to a figure well under the limits of accuracy of an hydraulic computation such as attempted.

The existence of a net southerly flow is not apparent from physical and chemical observations. Tidal currents in the upper East River as shown by government charts have velocities and durations that indicate a net flow northward to the Sound. In this part of the harbor there is little difference in salinity between the top and bottom samples so that the evidence of surface currents may not be disregarded. Salinity gradients through the harbor and Long Island Sound show at times as much as 10 per cent land water in the Sound 90 miles from New York City, the apparent source of this land water being the Hudson River.

Referring to the salinity gradient on Chart 1 extending down the Hudson and out the Narrows to the Atlantic Ocean, it will be seen that the effect of the relatively small land water flow from the Passaic River (about 7 per cent of total land water) entering between Robbins Reef and the Narrows is apparent, but there is no noticeable effect from a much larger flow of sea water reputed to enter from the Sound. An interesting but perhaps not conclusive point shown on this chart is that the rate of increase in salinity in the Arthur Kill from Elizabeth to Tottenville over a course where we are assured that the land water flow from Newark Bay is toward Tottenville, corresponds very closely with the rate of salinity increase in the upper East River in the direction of Long Island Sound.

Referring to the curves for dissolved oxygen on the same chart, it would be expected that the mixing of the oxygen-depleted waters in the East River with the Hudson River water of higher oxygen value that would result from a large net southerly flow from the East River, would be reflected in a lower value of the Hudson River mixture in the Upper Bay. Such a condition is not apparent.

From the consideration of these facts that raise a grave question as to the theoretical basis for the existence of a net southerly flow of sea water from the Sound, and that the physical and analytical observations point rather

to a net northerly flow of land water from the Hudson River through the East River to Long Island Sound, we are inclined to believe that the net flow through the harbor is that due to the tributary stream and sewage flows, and that it will be proportioned between the Narrows and Throgg's Neck in accordance with the hydraulic characteristics of the channels. Should this be the correct view-point the computations involving about half the pollution considered would be in error as the direction of its influence and the times of contact would be different than assumed by Phelps and Velz.

The general methods used in balancing oxygen demands against sources of oxygen supply are sound, but many of the essential quantities entering the computation are not subject to exact determination with our present knowledge. It is felt that the lack of separate consideration of the oxygen demand of settleable solids has resulted in a lower total oxygen demand than may actually be exerted and will not disclose the full benefit that may result from sewage treatment. In the studies made by the Engineering Board of Review of the Illinois River in connection with pollution from the City of Chicago, methods similar to those used by Phelps and Velz were utilized, but the great importance of sludge deposits was emphasized.

Sewage is not a homogeneous fluid. Under conditions such as we have in New York Harbor settleable solids are deposited on the bottom, and colloidal matter and even matters in solution may also settle out in the form of sludge under the influence of salt water and natural purification. The value of 0.22 pounds of oxygen demand per capita per day that has been used is believed to correspond to the 20-day demand. Theriault has shown that the oxygen demand of sewage is continued beyond 20 days. It is indicated that the six months demand may be about 270 per cent of the 20-day demand.

It is obvious that the oxygen demand of solids deposited in the harbor cannot be computed on the same time basis as the liquid portions and that the oxygen demand of such portions will continue for a long period, eventually reaching much higher totals than the amounts assumed. It is also true that solids deposited in the colder weather may lie partly dormant under the low temperatures and become more active during the summer months thus adding to the summer demand.

The effect of oxygen absorbed in the air has been found both in Chicago and elsewhere to be of substantially greater importance than indicated in the computations. It is possible that this influence may be great enough to counter-balance the effect of sludge deposits which were not included in the computations.

The authors are to be commended for much careful and original work on a complicated and difficult problem. The paper will undoubtedly result in a better understanding of the forces involved. It should be helpful in

future studies that must be made in solving the great problem of pollution in New York Harbor. It is felt, however, that the computations as they now stand must be revised before they can be relied upon as a true summation of the natural processes that influence the condition of the harbor waters.

Authors' Closure

BY EARLE B. PHELPS AND CLARENCE J. VELZ

The authors appreciate Mr. Gould's analysis and discussion of their paper, especially in view of his detailed knowledge of the New York Harbor situation.

With regard to the extent and direction of the net flow through the East River we are in no way prepared to defend the assumptions made in our paper. We have accepted Professor Mitchell's conclusions which, we believe, have at least not been contradicted by any later work of the U. S. Coast and Geodetic Survey, and which were checked and considerably strengthened by a rather detailed study made in the office of General Black in the course of the preparation of the Black and Phelps report. This latter study utilized the more recent data obtained by the U. S. Army Engineers' Office in connection with river and harbor improvement work then under way.

On the other hand, Mr. Gould's evidence against the net southward flow is not very impressive. The salinity gradient sloping upward from the Battery to the Sound is a necessary condition resulting from the very large tidal movement of which the net flow involved in the present discussion is, as Mr. Gould points out, only 5 per cent. Quite apart from any question of net flow, water from the Battery passes well beyond Hell Gate on one-half tide, is mixed with the waters from the Sound on the next half tide and passes well beyond Throgg's Neck on the third. Under these conditions a gradient is necessarily set up in which land water from the Hudson would move into the Sound against a net movement of the stream just as sea water runs up the Hudson River. In view of the large water-shed tributary to Long Island Sound east of Throgg's Neck, the land water values observed further to the east can hardly be attributed to the influence of the Hudson River.

The evidence presented upon the basis of the dissolved oxygen gradient in the Bay is equally unconvincing. South of the Battery the Bay comes under the influence of the oxygen resources entering by way of the Narrows resulting in a steep oxygen gradient upward toward the Narrows and this gradient dominates the picture in this stretch. We clearly show, however, that the lower Hudson values are in fact reduced by the East River pollu-

tion but here again the tidal oscillation of about 8 miles is of much greater influence than the assumed southward flow of the East River.

We wish it to appear, however, that we are much more interested at the present time in developing a technique for the analysis of this complex problem than in the essential accuracy of any of the physical data involved. If the method of analysis be sound, the resulting formulas are sufficiently flexible to be adjusted at any time to any required modification of the assumptions and, in this case in particular, no difficulty will be experienced in refitting our analysis to any other assumed condition of flow in the East River. Obviously, it is quite essential to establish the actual physical facts before proceeding to any final solution.

With regard to the biochemical data employed in our paper, we are upon somewhat more secure ground. Separate consideration of the oxygen demand of the settleable solids is not justified. The data of our Tables IV, V and VI indicate a reduction of about 80 per cent of the total demand down to the Narrows. We may assume that a fairly efficient sedimentation of sewage would reduce its demand by about 30 per cent. Assuming such sedimentation to take place in the Harbor waters, with subsequent complete oxidation of the settled material, the net effect would be to raise the demand-satisfied value from 80 per cent to 86 per cent of the total population. The actual effect of sedimentation probably lies somewhere between these two end conditions and we believe it to be much better represented by neglecting sedimentation in toto. The emphasis placed upon sludge deposits in the case of the Chicago Drainage Canal and Illinois River was justified under a set of conditions in which there was practically no oxidation and practically complete sedimentation. In New York Harbor the local effects of sludge deposits are striking but the average effect upon the Harbor condition is slight as compared with the effect of the same material passing through without sedimentation.

With regard to the 0.22 lb. of oxygen demand per capita, this is the ultimate, not the 20-day demand, and refers, as is customary, to what Theriault has since termed the "first stage." The much higher values obtained by him in the second or nitrification stage are not applicable to any body of water like New York Harbor and in particular are not applicable to sludge deposits.

Re-aeration in New York Harbor has been a subject of controversy for about 25 years and the senior author's views are sufficiently well known and have been sufficiently defended on previous occasions. They are based upon a doctrine of physical and mathematical facts which are rationally sound and have been experimentally verified. The inherent difficulty in their acceptance and the apparently contradictory results presented by various observers are due to the fact that the applications of these identical principles to streams like the Ohio River and to a body

of water like New York Harbor lead to rather astonishingly different absorption values. All these values, however, when properly analyzed and interpreted are in conformity with the theory that has been developed.

In conclusion, the authors are in full agreement with Mr. Gould's closing paragraph. We hold our present results to be merely another step toward the analytical solution of this complex problem. We need more and better chemical data, more data upon the basic assumptions concerning the tidal circulation and, without a doubt, more and better mathematical analyses. Our efforts are presented rather with the desire to stimulate just such helpful discussion as Mr. Gould has presented than in any fond hope that they might be either complete or final.

Editorial

Sludge Disposal Not Standardized

Just when we were beginning to think that a standard procedure had been developed for disposal of sludge, consisting of digestion and drying on sand beds, new methods appear which indicate a trend toward mechanical dewatering and incineration. Chicago has led in this revolt from established practice, although as yet only on an experimental scale. It is expected, however, that a large-scale sludge incineration plant may be in operation, within the next year and one-half, in which sludge will be filtered and burned. The experimental work to date has actually been on a very large scale, with a daily capacity of twenty or more tons of dry sludge.

Milwaukee has endorsed this procedure for enlargement of its present capacity for sludge disposal, and other large projects are favoring this method.

Incineration also provides a satisfactory procedure for disposal of chemically precipitated sludge, which is somewhat of a problem, as the organic matter precipitated by the chemicals is completely undigested and not in a very satisfactory condition for biological digestion. A chemical process can hardly be called modern if no provision is made for sludge disposal beyond drying on sand beds or filter-pressing, since sand-bed drying is neither new nor, in all probability, satisfactory as a means of disposal of fresh solids, even if chemically precipitated. Filter-pressing alone of chemically precipitated sludge, even with vacuum filters, if followed by dumping of the cake, can hardly be called modern, as it was done for years at Worcester and Providence, but abandoned some years ago. A modern chemical process must certainly go beyond filtration of sludge, and logically the next step is incineration.

Most of the chemical processes have not as yet included this ultimate step because of the additional expense involved. The Guggenheim process, however, contemplates incineration with leaching of the ash with sulphuric acid for recovery of ferric sulphate. Other chemical processes should likewise include the cost of incineration in estimates of the cost of sludge disposal.

There is a rather sharp division of opinion as to the fertilizing value of sewage sludge. Milwaukee has the best record of accomplishment in conservation of sludge as a fertilizer, and on a smaller scale other cities have reclaimed some sludge as a low-grade fertilizer, as at Dayton and Grand Rapids, but Chicago, Cleveland and Indianapolis have not been persuaded to adopt fertilizer production by Milwaukee's experience.

Sludge digestion for small and medium-sized plants still appears to be most popular, at least for settled sludge alone, but for digestion of mixed settled and activated sludge, some difficulties have arisen such as excessive moisture content and concentrated supernatant liquor. The last two years have witnessed considerable progress in overcoming the latter of these difficulties, with best modern practice exemplified by operation at Peoria as described in this issue (page 623).

It is stimulating to note the dissatisfaction with the present procedures and the effort to find a better solution of the problem of sludge disposal. This problem will probably remain for a good many years to come, but at least it has not run into a rut of standardization, and some forward-looking engineers are not disposed to accept the *status quo* as the solution of the problem.

Building Sewers to Relieve Unemployment

The unique social experiment tried out at Marblehead for relief of unemployment, as described by Mr. Haley (page 655) by construction of needed sewers, is worthy of serious consideration by other cities with similar problems. The sensible planning and prosecution of this project reflect the thrift and independence for which New England is noted. The workers numbered 250, and Mr. Haley states that they represented an average occupational cross-section of the town, although we might expect, in these times, to find more than one real estate agent.

The results of the project were tangible and successful. Although the total cost using hand labor was $105,000, whereas it was estimated that the same work accomplished by contract and modern machine equipment would have cost only $85,000, the cost of unemployment relief would have added $30,000 to the $85,000, and the total cost would have been $115,000 instead of $105,000. Although a saving of only $10,000 may not seem large, there were further returns such as the heartening of the spirits of the workers, the completion of an essential municipal improvement and the satisfaction that the labor had been expended on home town improvement. Such returns are certainly preferable to the outright payment of a dole.

Employment Service

(1) DESIGNER thoroughly experienced in design and construction of sewage treatment plants. Just completed one year with general contractor on sewage treatment plant job. Previous four years drafting and design work in sanitary engineering. Total experience twelve years since graduation. Age 37. Married. Assoc. Mem. A.S.C.E.

(2) M.S. in SANITARY ENGINEERING, 1932, Michigan State College. Seven years with the Michigan State Highway Commission. Municipal engineering, including construction of water mains and sewers. Assistant instructor in sewage operators school. Publications on trickling filters and stream pollution. Age 31. Married.

(3) SANITARY ENGINEER, graduate M. I. T., four years experience in design of sewers and sewage treatment works, five years experience in investigating industrial wastes, designing and operating sewage testing stations, and investigating and developing methods and apparatus for sewage treatment. Three years as asst. supt. of large activated-sludge plant. Desires position to design or operate treatment works or to aid in the development of new processes and apparatus for sewage treatment. Age 36. Married.

(4) CHEMIST AND BACTERIOLOGIST, university graduate, six years superintendent of water filtration plant, past five years in sewage works laboratory, in charge of plant control. Recent experience in sludge filtration and disposal. Age 37. Married.

(5) SANITARY ENGINEER, M.S. from Michigan State College. Experience in highway and railway work. University work in soil bacteriology. Age 25. Single.

(6) SANITARY CHEMIST AND BACTERIOLOGIST, B.S. in Chemical Engineering, M.S., four years experience in sewage and water treatment, principally research and development at state experiment station, recently with prominent consulting sanitary engineer, publications. Age 27. Single.

(7) SANITARY ENGINEER. More than ten years experience in designing, building and servicing mechanical equipment used in sewage treatment works, such as screens, clarifiers, digesters, aerators and pumps. Design and construction of paper mill and beet sugar factory. Age 37. Married.

(8) SUPERINTENDENT of sewage works. Ten years experience as Superintendent of small Iowa sewage treatment plant. Has also had charge of municipal garbage incineration works. References. Age 39. Married.

Proceedings of Local Associations

New England Sewage Works Association Spring Meeting

Woonsocket, R. I., May 1, 1933

The Spring Meeting of the New England Sewage Works Association was held May 1, 1933, at the Hotel Blackstone, Woonsocket, Rhode Island. One hundred members and guests were registered for the various sessions.

The meeting opened at 11 A.M., President Roy S. Lanphear, of Worcester, presiding. President Lanphear announced that the Executive Committee, since the time of the last meeting, had appointed a special committee to coöperate with a similar committee of the Boston Society of Civil Engineers to consider the matter of sewer rental charges in New England. This Committee consisted of Harold S. Crocker, *Chairman*, Stephen DeM. Gage, John H. Brooks, Jr., William R. Copeland and Henry R. Buck. Mr. Copeland reported for the Committee that due to the limited possibilities of applying the sewer rental system in New England the Committee felt that there was little for them to do and therefore recommended that the Committee be discharged. This report was accepted and the Committee discharged with thanks.

President Lanphear announced that it had been suggested that the Association conduct a school for sewage works operators and asked for discussion of this project from the floor. Following discussion by E. Sherman Chase, A. D. Weston, E. C. Johnson, and J. H. L.Giles it was moved and seconded that the chair appoint a committee to study the matter of a sewage works operators' school and to report at the next meeting of the Association. The President appointed the following Committee: Professor Gordon M. Fair, *Chairman*, Warren J. Scott, Eskill C. Johnson, A. D. Weston and F. W. Gilcreas.

The Treasurer reported a balance in the treasury of $235.12. The Secretary reported that the membership at present was 117, nine new members having been received since December 31, 1932, and five members having resigned, the dues of twenty-eight members remaining unpaid to date.

The Committee on Sewage Sampling presented its final report, embodying changes suggested at the last meeting. This report was accepted without being read and the Committee was discharged with thanks for its very excellent work.

President Lanphear introduced the Honorable Felix A. Toupin, Mayor

of Woonsocket, who spoke briefly, welcoming the Association to Woonsocket.

The first paper of the morning session, "Pumping of Sewage and Sludge," was presented by Mr. Charles E. Greene, of Metcalf & Eddy, Boston, Mass.

Mr. F. W. Haley, of the office of Frank A. Barbour, Boston, Mass., presented the second paper entitled "Sewer Construction Using Welfare Labor." Both of these papers provoked considerable discussion from the floor.

A description of the Woonsocket Sewage Treatment Plant was given by Mr. Edwin K. Marrah, Supt. of Sewer Division, Woonsocket.

Mr. Michael J. Blew of Philadelphia was unable to be present at the meeting to give his paper, "Observations on Incineration of Sewage Sludge," scheduled for the morning session.

The morning session adjourned at 1 P.M. for luncheon at the Hotel Blackstone.

Following luncheon the members and guests assembled for Round Table Discussion of operating experiences in sewage treatment plants. The subject matter for Round Table Discussion was introduced by Mr. L. W. Van Kleeck, Asst. Engr., Conn. Dept. of Health, who presented a paper "Notes on Operation of Sewage Treatment Plants."

Following the Round Table Discussion the session adjourned to the Woonsocket Sewage Treatment Plant, where those attending the session had the opportunity to inspect the plant and observe the treatment of sewage by the activated-sludge method.

Members and guests assembled at the Hotel Blackstone for dinner at 6 P.M. Following dinner the Association heard a most interesting address by Professor Wilson G. Smillie, of the Harvard School of Public Health, on "Field Work in Public Health from the Tropics to the Arctic Circle."

President Lanphear announced that the Annual Meeting of the Association would be held at Worcester during the month of October, 1933, following which announcement the meeting adjourned.

F. W. GILCREAS, *Secretary-Treasurer*

California Sewage Works Association Spring Conference

San Luis Obispo, May 5 and 6, 1933

The California Sewage Works Association held its Spring Conference May 5 and 6, 1933, at the Anderson Hotel in San Luis Obispo. Friday morning members and guests were escorted by automobile caravan on an inspection tour of the sewage treatment plants at San Luis Obispo and

Arroyo Grande. A novel feature of the latter is the discharge of effluent through a header pipe with ten outlets which are used in rotation, one each day, giving nine days' rest between periods. The beds are simply channels which have to be cleaned at intervals of about sixty days. The plant is at ground level and sludge beds are in excavation. Natural sand is used for drying beds. The party continued to Pismo Beach Sanitary District serving a population of 1500 and consisting of a settling tank with 12-inch gravity outfall to the ocean 1365 feet beyond high tide. Uranin dye was added to the sewage at 10:20 A.M. and it appeared in the ocean at 11:00 A.M. just as the visitors arrived at the plant.

Friday afternoon President Jacobson called the meeting to order and a symposium on chemical precipitation was opened with an historical review, by Professor Leon B. Reynolds, of the work done by investigators abroad as well as in America. The following papers were presented: "Simplified Sewage Treatment with Ferric Chloride Developed at Palo Alto," by Ralph A. Stevenson, and "Recent Developments in the Chemical Treatment of Sewage in the United States Outside of California," by Charles Gilman Hyde. Of the 18 processes reviewed he mentioned particularly the Streander Process at Philadelphia, the Cabrera-Maier Process at Wilmington and the use of ferric chloride at Oklahoma City.

In a symposium on incineration dealing with screenings, skimmings and sludge, three papers were presented by J. J. Jessup, City Engineer of Los Angeles, A. P. Banta, Assistant Engineer, Los Angeles County Sanitation Districts, and R. F. Goudey, Sanitary Engineer, Los Angeles Water Department.

Under the general title "Hazards," two papers on cross connections between water and sewer systems were presented. Different types of connections and plumbing fixtures were discussed by Ray L. Darby of the Los Angeles Water Department. Operating conditions in a water system which would give partial vacuum were described by C. W. Sopp of the Pasadena Water Department.

Mr. S. H. Ash, District Engineer of the U. S. Bureau of Mines, summarized the work of his department in a paper on "Detection and Measurement of Gases." Mr. C. H. Fry, Superintendent of Safety, State Industrial Accident Commission, presented a paper entitled "Hazards, Gas Masks and First Aid."

Following the dinner Friday evening there was a discussion of activated sludge patents by T. R. Haseltine, Chester A. Smith and F. V. Hammerly. The earthquake in Southern California with particular reference to breaks in water and sewer lines was discussed by Fred Bowlus and J. A. Harmon. Mr. Robert Linton and C. C. Kennedy reported on methods of obtaining R. F. C. funds and on the status of Assembly Bill 980 involving the Sewer

Revenue Bond Bill, which was passed by the Assembly and favorably reported out of committee in the Senate.

A feature of the dinner was the presentation of the Award of Merit, given each year by the Wallace and Tiernan Company, to T. R. Haseltine, operator of the Salinas plant.

On Saturday morning committee reports were presented, and the program was continued with a discussion of the papers delivered the previous evening. Two interesting papers on "Changes of Character of Sewage" were prepared by F. S. Currie and W. C. Roberts. The discussion which followed was led by A. M. Rawn, C. C. Kennedy and A. A. Taylor. A paper entitled "Keeping Power Bills Down" by Earl E. Thomas, General Electric Company, Los Angeles, was abstracted by C. G. Gillespie, and H. K. Palmer presented another paper, "Keeping Down Power Costs."

The final paper on the program, "The Design of Gas Collection Systems for Sewage Works," was read by T. R. Haseltine of Salinas. The paper proved to be a very complete statement of the problem of gas collection and included an extensive bibliography. E. A. REINKE, *Secretary*

New York State Sewage Works Association Spring Meeting

Rochester, June 9 and 10, 1933

The Spring Meeting of the New York State Sewage Works Association was held at the Hotel Seneca, Rochester, June 9 and 10, 1933. One hundred and thirty members and guests attended.

Following registration and a brief business meeting Friday morning two technical papers were presented. "Some Things That Have Been Learned About Sewage Aeration by Diffused Air" was given by Frank C. Roe, Engineer, The Carborundum Company, Niagara Falls, and was discussed by Mr. A. B. Holmstrom of the Norton Company, Worcester, Massachusetts. Mr. Arthur Wright of the Arthur Wright Associates discussed "Vacuum Filtration in Sewage Treatment," by William Gavin Taylor, Consulting Engineer, Newark, New Jersey.

The afternoon session opened with a paper by L. A. Bergman, Director of Public Works of Jamestown, on "Sewage Treatment at Jamestown, N. Y.," with a discussion by H. Burdette Cleveland, Designing Engineer of that city. This was followed by a symposium on "The Operation of Small Sewerage Systems and Treatment Plants," led by William A. Ryan, Consulting Chemist of Rochester. The following topics were discussed: "Separate Sludge Digestion," Arthur Gary, Fairport; "Foaming Troubles

and Their Correction," Harold Deming, East Rochester; "Embellishment of Plant Grounds," William Eckhart, Rochester; "Covered Sludge Drying Beds and Sludge Drying," A. W. Evans, Tonawanda; "Importance of Cleanliness About the Plant," A. H. Hale, Town of Brighten; "Prechlorination," John C. Strowbridge, Dundee; and "System in Operation and Operating Records," which was assigned to John Nelson of the Woodlawn District, Hamburg, N. Y., and in his absence briefly discussed by Mr. E. R. Cotton.

The afternoon session closed with a paper on "The Selection and Maintenance of Mechanical Sewage Equipment," by John Lewis, Director, Bureau of Maintenance and Operation, Department of Public Works, Rochester.

A lively Question Box and Round Table discussion conducted by Morris Cohn of Schenectady followed Saturday's "sunrise breakfast." The morning session closed with two papers describing the plants to be visited, one by Glenn D. Holmes, Consulting Engineer of Syracuse, on "Features of the Revamped Plant at Newark," and the other by R. G. McDonald, Engineer of the Village of East Rochester, on "Operating Experiences at the East Rochester Plant," each of which was briefly discussed.

The following resolution was passed by the Association:

WHEREAS, indications point toward the early passage of the National Recovery Act, which is being formulated to stimulate industry and relieve unemployment, and

WHEREAS, the construction of public works projects offers one of the best means of achieving both of these objects, and

WHEREAS, the construction of sewerage and sewage treatment and other sanitary works promotes public health, conserves natural resources and offers an opportunity to construct installations of permanent value,

Now, therefore, be it resolved, that the New York State Sewage Works Association assembled at its Spring Meeting in Rochester, June ninth and tenth, 1933—urge that all municipalities in New York State needing sewerage and sewage treatment improvements take immediate steps to make studies and prepare plans for the construction of such works, with a view toward making applications for the necessary funds under the proposed National Act.

The next meeting of the Association will be held in White Plains in October on a date to be fixed later. A. S. BEDELL, *Secretary-Treasurer*

Notice of the Seventh Annual Conference Pennsylvania Sewage Works Association

State College, September 5, 6 and 7, 1933

The Seventh Annual Conference of the Pennsylvania Sewage Works Association will be held at State College, Pennsylvania, on September 5, 6, and 7, 1933. The following program has been arranged:

TUESDAY, SEPTEMBER 5

1:00 P.M.	Registration.
7:00 P.M.	"Demonstration and Instruction of Sewage Plant Tests," F. E. Daniels, Chief, Industrial Waste Section, Pennsylvania Department of Health.

WEDNESDAY, SEPTEMBER 6

8:30 A.M.	Registration.
9:30 A.M.	Address of Welcome.
9:45 A.M.	"Trouble Hour Symposium," A. B. Cameron, Erie; Roy L. Phillips, Meadville; Frank Altemus, Norristown; R. R. Cleland, State College; C. F. Grace, Polk; F. M. Harper, Butler; L. E. Burnside, Sharon; C. S. Boettger, Delaware County Prison Farm.
11:15 A.M.	Business Session.
12:00 Noon	Recess.
1:15 P.M.	"Operating Experiences in New York State," Charles C. Agar, Assistant Sanitary Engineer, New York State Department of Health, Albany, N. Y.
2:05 P.M.	"Excessive Ground Water in a Sewer System and Its Effect on Sewage Plant Operation," C. A. Emerson, Jr., Fuller & McClintock, Engineers, New York.
2:55 P.M.	"Application of the Sewer Rental Law," John L. Fortis, Director, Legislative Reference Bureau, Harrisburg.
3:45 P.M.	"Experiments Upon the Heating of Sludge to Determine the Heat Transfer Coefficient from a Heating Coil to Sludge," E. R. Queer, Engineering Experimental Station, Pennsylvania State College, State College.
4:15 P.M.	Recess.
7:00 P.M.	Dinner, Round Table Discussion and Entertainment, led by H. E. Moses, Assistant Chief Engineer, Pennsylvania Department of Health.

THURSDAY, SEPTEMBER 7

9:00 A.M.	"Sewage Collection and Disposal at Lancaster, Pa.," J. F. Laboon, J. N. Chester Engineers, Pittsburgh.
10:00 A.M.	"The Oxygen Demand Test and Its Application to Sewage Treatment," J. K. Hoskins, Sanitary Engineer, U. S. Public Health Service, Cincinnati, Ohio.
11:00 A.M.	"The Mechanical Dewatering of Sewage Sludge on Vacuum Filters," E. D. Flynn, Oliver United Filters, New York.
12:00 Noon	Adjournment.

Book Reviews

Sewerage and Sewage Treatment (Kanalization und Abwasserreinigung). By W. Geissler. Julius Springer, Linkstrasse 23, Berlin W 9. 31.5 Marks.

This 378 page book by Prof. Geissler, of the Dresden Technical School, is the latest German text on sewerage and sewage treatment. The author has had experience as director of public works in Nordhausen and Duisberg (the latter in the Ruhrgebeit) and formerly was associated with Director Bredtschneider at Berlin.

The first 202 pages deal with sewerage, the following 140 pages discuss sewage treatment. There are three appendices giving specifications for sewers and sewer construction as adopted by German municipal and contractors' associations. Finally there is a bibliography of 454 references.

The book is devoted almost exclusively to German practice. The author is apparently more deeply conversant with sewer design and construction than sewage treatment, although the essentials of present-day German practice in sewage treatment are covered fairly well. It is unfortunate that the extensive development of activated sludge plants in England and the United States is totally ignored, while small or semi-experimental German plants are described in some detail. The chapters on settling of sewage and digestion of sludge are more satisfactory, since German practice has developed more intensively along these lines than in the field of biological treatment. The short description of several sewage districts (Emscher, Ruhr and "Weisse-Elster") are of interest.

The main and unique value of the book, however, lies in the first section, on sewerage, with particular reference to the design of intercepting sewers, rainfall and runoff studies, sewer materials, outfalls, siphons, drainage systems and pumping stations. The drainage systems of Frankfort, Leipzig, Berlin and Duisberg are shown in several plates among the 302 illustrations with which the text is liberally interspersed.

As a textbook or handbook of the status of sewerage and sewage treatment in Germany, this book can be highly recommended. The material is well chosen to demonstrate the various types of design and equipment in Germany, although not particularly informative about any specific or outstanding installations. The material is up-to-date and the construction and appearance of the book are excellent. F. W. MOHLMAN

Symposium on Stream Pollution and Disposal of Industrial Wastes. *Transactions* of the American Institute of Chemical Engineers, Vol. XXVII, 1931. D. Van Nostrand, New York. $6.00.

The 1931 *Transactions* of the American Institute of Chemical Engineers contains seven papers on stream pollution, occupying 153 pages of this 425 page book. The remaining papers deal with purely chemical engineering subjects, such as the drying of solids, heat transfer and chemical engineering education.

The papers on stream pollution are by Robert Spurr Weston, "The Use, Not the Abuse of Streams"; W. L. Stevenson, "The Sanitary Conservation of Streams by Coöperation"; Willem Rudolfs, "Stream Pollution in the State of New Jersey"; and Thorndike Saville, "Administrative Control of Water Pollution." The papers on disposal of trade wastes are by William S. Wise," Work of the Connecticut State Water Commission"; Edward Bartow, "Disposal of Wastes Formed in the Manufacture of Starch and Beet Sugar"; and Edmund B. Besselievre and Anthony Anable, "Liquid Wastes from Industrial Plants and Their Treatment."

The papers are somewhat general in scope, but contain information of value for those in administrative charge of stream cleaning or disposal of industrial wastes. The well-known Pennsylvania code for the sanitary conservation of streams has demonstrated the value of coöperation between industry and state authority; the Connecticut report summarizes the methods proposed for treatment of metal and textile wastes; the New Jersey situation calls for conservation of waters suitable for water supply, and diminution of the gross pollution of the larger rivers not considered suitable for water supply. The paper by Saville is a lengthy compendium of the status of Federal and State control over water pollution. The author recommends studies of water pollution from a national standpoint, and he also presents conjectural views on administrative reforms for better control of stream pollution.

Weston discusses standards of stream cleanliness; Bartow has studied in detail the products that may be obtained from beet sugar wastes, in particular mono-sodium glutamate, used extensively in Japan as a condiment, and now being introduced in this country. Besselievre and Anable discuss briefly the character of wastes from paper mills, packing-houses, tanneries, glue factories, textile plants, steel plants, the canning and dairy industries and gas plants. Diagrammatic flow-sheets are shown for treatment of such wastes.

F. W. MOHLMAN

Reviews and Abstracts

H. W. STREETER

Fortieth Annual Report of the West Riding of Yorkshire Rivers Board April 1, 1932, to March 31, 1933 Wakefield

By John Garner, *Chief Inspector*

The size and importance of the West Riding of Yorkshire Rivers Board in England is not fully appreciated in the United States. The West Riding lies in the north central part of England, west of Manchester. The district is approximately fifty miles wide by eighty miles long, and has a population (1931) of 3,437,368. The population is largely concentrated along the valleys of the Rivers Aire, Calder and Don, with the urban population largely in 10 cities or boroughs, ranging in size from Sheffield, Leeds, Bradford and Huddersfield, with populations from 517,000 to 113,000, through Halifax, Rotherham, Dewsbury, Barnsley, Wakefield and Doncaster, with populations from 98,000 down to 63,000.

The West Riding has 430 sewage treatment works in operation. Most of these were constructed during the percolating-filter era, that is, before the processes of bio-aeration and activated sludge had been developed. Nevertheless, there are now nine works where Haworth's (Sheffield) bio-aeration system is in operation, and three at which the "Simplex" aeration process is used.

Many of the sewage treatment works receive large amounts of industrial wastes. The most notable is the wool-scouring waste present in the Bradford sewage. The Esholt plant at Bradford is unique in several respects, in that wool grease is recovered by acid "cracking" and the effluent is treated on 53 acres of coal filters. (*Editor's Note.* A very complete description of this plant has just appeared in *The Surveyor* for July 14, 1933, page 33. An abstract of this article will appear in our next issue.)

The Leeds plant at Knostrop is one of the largest percolating filters in England. The effluent is reported as not always satisfactory, containing too much matter in suspension. A new sludge pressing plant is to be installed.

The Sheffield bio-aeration plant is well known to American sewage chemists and engineers. Mr. John Haworth, the designer of this plant, is President of the Institute of Sewage Purification, formerly the Associa-

tion of Managers of Sewage Disposal Works. Two new works are being constructed at Sheffield to replace obsolete works at Woodhouse and Woodhouse Mill. The new works are on the bio-aeration system, but circulation in the aeration tanks will be by axial-flow pumps instead of by paddles. Separate sludge digestion tanks have also been provided.

The Huddersfield sewage contains a large volume of chemical effluents from dye plants. The chemical wastes are conveyed to the sewage plant by separate sewers, and pre-treated before final treatment in two Haworth bio-aeration units and also on 10 acres of percolating filters. A by-product plant for the recovery of grease and the production of fertilizer from sewage sludge has been in operation since 1915.

The sewage works at Halifax include a large installation of "Simplex" units. The present unit is capable of dealing with a flow of 20,000 gallons per hour and this is being extended to handle 70,000 gallons per hour. These units are intended to deal with peak flows during the day time, when large volumes of trade refuse are discharged into the sewers. Sludge is pressed and treated for grease and fertilizer manufacture.

A small plant at Ravensthorpe, of the Dewsbury Corporation, receives an abnormal sewage, consisting of one-third sewage and two-thirds textile wastes. By use of special equalizing tanks the settled wastes have been treated satisfactorily on percolating filters.

Smaller plants throughout the West Riding have similar contributions of industrial waste, which present varied and difficult problems for Mr. Garner and his associates. The more important wastes mentioned and described in the report include those from textile trades, wool scourers, artificial silk manufacture, gas and coke plants and a beet sugar plant at Poppleton. The disposal of ammonia liquor from gas and coke plants still remains quite a problem, since the manufacture of sulphate of ammonia cannot be carried on at a profit, owing to the cheapness of the synthetic product made from atmospheric nitrogen. The 1931 Report dealt with experimental work on these wastes and several methods of disposal were suggested (*This Journal*, November, 1932, page 1094).

The treatment of abnormal sewages of such varied types has been a very difficult and prolonged problem in the West Riding, but during recent years the improvement in the condition of the rivers is becoming noteworthy. The Upper Aire is a clean stream capable of supporting fish life, but below Bradford and Leeds it deteriorates markedly until self-purification becomes effective in the lower stretch of the river, just above its entrance into the River Ouse. Other river areas have difficult local problems in the disposal of industrial wastes, particularly along Spen Beck and Batley Beck, tributaries of the Calder. Many projects are recommended for handling these wastes, which will be installed when funds are available.

Research on special problems in sewage treatment and trade waste disposal has been started at various sewage works in the West Riding, as a part of the larger program of the Institute of Sewage Purification. The following problems are being investigated: Sludge digestion and drying; trade refuse problems; settling tank design; prevention of fly nuisance on percolating filters; and chlorination of sewage.

Meetings of the works managers are held twice yearly; there are about 90 members.

The West Riding Rivers Board personnel consists of the chief inspector, five clerks, nine inspectors, one biologist, four associate chemists and two laboratory assistants. The total expenditure in the year 1932–1933 was £10,310.

Mr. Garner is to be congratulated upon this interesting report. The West Riding Rivers Board presents an outstanding example of the management and coördination of a large sewage and waste treatment project in an intelligent and efficient manner. F. W. MOHLMAN

Symposium on Sewage Disposal
British Institution of Chemical Engineers
London, England, January 25, 1933

British Practice in Sewage Disposal

BY H. C. WHITEHEAD AND F. R. O'SHAUGHNESSY

Tracing the history of sewerage and sewage disposal, the authors cite numerous instances of sewers in ancient times.

With the invasion of Britain by the Romans, many sanitary appliances and the water carriage of wastes were introduced. Evidences of these are still to be seen in various ruins over England. Following the fall of Roman rule the population of the islands became agrarian in character and it was not until the beginning of the 19th Century that the concentration of population in cities began to cause serious difficulty. This culminated in the cholera epidemic of 1831, which caused 50,000 deaths in the United Kingdom. With the re-invention of the water closet early in the 19th Century, came also the development of sewers and the pollution of rivers to an increasing degree. Where these were used as sources of water supply, the results were disastrous. Two serious outbreaks of cholera occurred in 1850 and 1853, and these led to the construction of intercepting sewers in the larger towns. This concentrated the filth and caused investigations on sewage disposal to be made, the first commission being appointed in 1857.

Disposal by irrigation of land was generally adopted following the report of the earlier commission. It was not until about 1870 that experiments on chemical treatment of sewage with lime and intermittent filtration through soil were made by Frankland. Experiments at Lawrence, Massachusetts, resulted in increasing the size of the filtering medium, and this gave rise to the necessity of better distribution of sewage over the filter bed and to better clarification by chemical precipitation prior to filtration. The modern trickling filter was well developed by the beginning of the 20th century, including such features as traveling distributors, etc.

The septic tank introduced by Cameron at Exeter in 1896 was used extensively for a decade or so and is still advantageous for small installations.

Sedimentation was used first in conjunction with land treatment in the 1860's and later, both with and without chemical treatment to reduce the load on secondary treatment. At present, sedimentation tanks with a capacity of $^1/_2$ the dry weather flow are commonly used for storm flow tanks. The use of multiple sedimentation tanks for balancing the effect of variations in strength and flow of sewage, and the use of longer retention periods as an economic unit of sewage treatment, merit consideration.

Screens and grit chambers were the logical solution to difficulties caused by grit and large particles in sedimentation tanks, pump equipment, etc. Elaborate screening with fine screens has not been adopted widely in Britain.

Chemical precipitation, excepting the use of acids to "crack" industrial soaps, is not used extensively. Chemicals, however, such as chloride of lime and chlorine, are being utilized for the prevention of nuisances.

Although many experiments were made on the purification of sewage by aeration from 1893 on, it remained for Ardern and Lockett in 1914 to develop the first practical method by their use of activated sludge combined with aeration. Haworth in 1921 developed an alternative method of aeration and agitation by the use of paddle agitators and later Joshua Bolton developed the Simplex system. Many examples of all three types are to be found in Great Britain. An interesting modification of this process consists of partial treatment of the settled sewage with 2 to 3 per cent of activated sludge by volume for 1 hour or so, resulting in 40 to 50 per cent removal of "oxidizable impurity." Reconditioning of sludge by 6 to 9 hours' aeration is necessary but the process shows less sensitivity to upsets by industrial wastes. In regard to the high nitrogen content of activated sludge, experience at Birmingham has shown beyond doubt that ammonia and other materials are adsorbed from the sewage liquor by the activated sludge and are integrated by a synthetic process into the flocs of the activated sludge.

Separate digestion of sludge was installed on a large scale at Birmingham

between 1911 and 1914 following experiments as far back as 1908. It was not until 1922 that the next large plant, at Bath, was installed. Steady developments in this line are expected in the future. From the first, two-stage digestion with heating was practised at Birmingham. General experience has shown that a large mass of ripe sludge in proportion to the crude sludge is necessary, that high water content affects the economy and tends to produce volatile sulphides, that temperature adjustments are most economical at the beginning of digestion and that the pH should be between 7.5 and 7.8. "Our experience . . . shows that the digested product may be a far more desirable material from the farmer's point of view than the original crude sludge." At the Saltley works at Birmingham, sludge gas is collected under floating gas collectors and is utilized in engines having a total of 950 B. H. P. Waste heat from the engines is used to heat water circulated from the digestion tanks through heat exchangers.

R. W. KEHR

Sewage Treatment in America

BY L. R. HOWSON

Sewage treatment in America has been advanced largely through research by state and national experimental stations, pioneer work by the larger cities, research foundations at institutions and more recently by sewage works associations, of which there are now sixteen, and by contributions from capable technical operators of smaller plants. Many European developments have been adapted to local conditions. Sewage treatment in America is still in its infancy as all cities along the larger rivers still discharge their wastes untreated and until recently Baltimore was the only large seaport treating its wastes.

Trends in American Practice

1. Activated sludge in the larger cities, with sprinkling filters also used in cities of 250,000 or less.
2. Fine screens have been superseded by 30 to 60 minutes' sedimentation as treatment, preliminary to activated sludge.
3. Spiral flow diffused air for larger, and mechanical aeration for smaller, installations of activated sludge.
4. Digestion of mixed raw and activated sludge.
5. Large scale investigation of vacuum filtration and incineration of sludge.
6. Mechanical removal of sludge from primary tanks and digestion in separate tanks with gas collection, heating and stirring practised.
7. Power-driven equipment for screening and grit removal.

8. Disposal of screenings, scum and even grit by incineration.
9. Higher standards of operating control.
10. Higher degree of purification required.
11. Improved appearance of plants.
12. Mechanization of operations and housing of screens, grit chambers and even tanks for convenience of operators.

Present Practice and Developments

Bar Screens.—Practically all installations now being built are mechanically cleaned. One of the newer types has the rake actuated by an increase in the differential head through the screen and operates only when cleaning is needed. Because of the efficiency of mechanical raking, there is a tendency to reduce bar spacings and intercept more material.

Disposal of Screenings.—Numerous installations of incinerators have been made, using sludge gas or oil for fuel and reducing the moisture content of screenings by drying, pressing, or centrifuging prior to burning.

Grit Chambers.—There are 52 mechanically cleaned grit chambers in America and Canada, practically all new installations being of this type.

Clarification.—Fine screens in conjunction with chlorination are used at two Great Lakes plants prior to dilution with lake water.

There is a decided tendency toward the use of separate digestion tanks instead of Imhoff tanks, the most notable exception to this being the Chicago West Side plant. There are approximately 800 units of mechanically cleaned clarifiers in the United States and Canada. These are of the revolving or straightline types, usually with intermittent sludge removal and a short detention period, *i. e.*, $1^1/_2$ to $2^1/_2$ hours ahead of trickling filters, or 1 hour average ahead of activated sludge. Scum collection is frequently practised with disposal of skimmings by incineration, burial or discharge to digestion compartments.

Sludge Digestion.—Separate sludge digestion tanks are usually covered and heated to 80–95° F. Thermophilic sludge digestion has not proved advantageous in practice, and at present no plant in this country is heating sludge higher than 100° F. Capacity of heated separate digestion tanks varies from $1^1/_2$ to $2^1/_2$ cu. ft. per capita but accumulated data indicate that 1 cu. ft. may soon be commonly used. Digestion in stages is practised to a limited extent, one four-stage plant having been recently built. Digestion of mixed raw and activated sludge has been found practicable in some places, requiring 2 to 3 times the capacity necessary for primary tank sludge. Disposal of supernatant liquor causes trouble, especially in single stage digestion with mixed raw and activated sludge. About 75 per cent of the separate digestion tanks built in the last 5 years have had fixed covers and most of these were provided with a stirring mechanism. There are more than 150 digesters with mechanical equipment and 35 installations

of Downes floating covers in this country. In America the average plant can produce sufficient gas to heat the digestion tanks and building, burn the screenings and still have a surplus.

Dewatering of Sludge.—Drying of sludge on sand beds is almost universally used for final dewatering. Covering of sludge beds with glass is increasing and at Chicago mechanical removal and loading of dried sludge is practised. Experimental work has been done at Chicago with a view to filtering, drying and incinerating undigested mixed primary tank and activated sludge. Under present conditions the production of fertilizer from activated sludge is uneconomical except under unusual conditions.

Sprinkling Filters.—Consistent progress has been made in the design, construction and operation of sprinkling filters, with the major developments in the following lines:

(*a*) Better floor systems for drainage and ventilation.

(*b*) Scientific selection of filtering media to avoid deterioration.

(*c*) Determination of filter loadings based on organic requirement as well as liquid volume.

(*d*) Studies to control pooling, fly nuisance and similar operating trouble.

Of thirty more important sprinkling filter plants, 35 per cent have stone depths less than 6 feet, 60 per cent less than 7 feet and 25 per cent over 8 feet. Of these, 50 per cent have a minimum stone size 1 in. or less, 25 per cent, stones of $^3/_4$ in. in the upper part of the filter and 15 per cent have a minimum size exceeding $1^1/_2$ in. There are only about 75 units of moving distributors.

Activated Sludge.—With a growing number of smaller plants, more study is being devoted to operating difficulties. All larger plants use diffused air, usually with spiral flow. Indianapolis is reducing a 20-day B. O. D. of 400 p. p. m. to a 5-day B. O. D. of 20 p. p. m. with $1^1/_4$ cu. ft. of free air and 8 hours' aeration. Final settling is almost universally done in mechanically cleaned tanks, one of the newer types operating on the suction principle.

Chemical Precipitation.—There has been a decided revival of interest in chemical precipitation. Dearborn, Mich., uses lime, macerated paper and ferric chloride with sedimentation and upward flow through a magnetite filter. In another recent process operated on an experimental scale the settled effluent passes through a sand filter, then through zeolite for recovery of the ammonia. A method of handling packing-house wastes with a B. O. D. of 1200–1800 p. p. m. consists of treatment with 1800–2500 lb. of chlorine per M. G. of sewage.

Chlorination.—Sterilization by liquid chlorine of crude sewage or plant effluent when discharged near bathing beaches or sources of water supply is widely practised. Chlorine is also used to prevent septicity in

outfalls and to reduce operating difficulties in the plants. One recent development is the use of $1^1/_4$ lb. of lime per pound of chlorine added, with a resultant decrease in the chlorine required and improved results.

Architecture and Landscaping.—In recent years greater attention has been given to the architecture of the plant and an attempt has been made to landscape the surrounding grounds. Improvement in the appearance of plants is general.

R. W. KEHR

German Practice in Sewage Disposal

BY DR. KARL IMHOFF

"Almost all towns in Germany are provided with sewage purification works but the degree of purification attained is less than in England because Germany possesses larger rivers."

Screening Plants.—Installed in 59 large and medium-sized towns, and treat sewage from a total of 5,500,000 people. New plants are infrequently built, as they accomplish little in comparison to their cost.

Grit Chambers.—These are nearly always installed in treatment plants and are constructed and operated to yield clean sand, either by high velocity flow, air agitation or washing.

Septic Tanks.—These installations number 25 municipal plants, treating sewage from an aggregate population of 400,000. Individual installations treat sewage from an aggregate of $1^1/_4$ million people.

Settling Tanks.—Two-story tanks have been adopted in 240 towns with a population of 5,500,000. There are 70 towns with separate sludge digestion treating sewage from 2,000,000 inhabitants. These latter have been of the Dortmund type until recently, when mechanical scrapers have been installed, along with heated separate digestion tanks. Mixing of digestion tank contents is unnecessary in heated tanks, but of some advantage in unheated ones. Gas production averages 14 liters per capita per day with ordinary sludge, and twice that amount for activated sludge. This amount of gas is sufficient to provide heat and power for an activated-sludge plant.

Sewage Farms.—These are used in 90 towns treating the sewage from 6,500,000. Purification is good but nuisances are common and preliminary treatment is being provided in many places.

Trickling Filters.—These have been adopted by 90 towns with a population of 1,300,000. Contact beds are in use at 17 towns with a combined population of 200,000, but are no longer being installed.

Activated-Sludge Plants.—Plants of this type are in use at 13 towns with a total population of 900,000. Compressed air is generally used either alone or in combination with mechanical agitation. Efforts are

being made to reduce the amount of sludge present in the aeration tank to a minimum. Excess sludge is usually pumped to the primary settling tanks with continuous removal therefrom. This doubles the gas yield but necessitates tripling the digestion capacity and quadrupling the drying bed area.

Fish Ponds.—These are used for final treatment in 12 places with a population of 1,000,000. An excellent effluent is produced with $^1/_{10}$ the area required for sewage farms.

Impounding Reservoirs.—These have been built in the Ruhr District. They contribute as much to purification as the 70 plants in the area and cost nothing, due to the income from water rights. R. W. KEHR

The Operation of Activated Sludge Plants Practically Considered

BY. R J. SPODE

(With an appended description of the Stafford Activated Sludge Purification Works)

BY W. PLANT

The Surveyor, **83**, 391–5 (April 7, 1933)

This paper was read March 18, 1933, at the Birmingham meeting of the Institute of Sewage Purification and was discussed quite extensively. The author sets down the fundamental requirements for successful functioning of the activated-sludge process as:

1. Intimate mixing of the sludge and sewage during aeration.
2. Preservation of aerobic conditions in the plant.
3. Sufficient reserve capacity to handle peak flows.
4. Regular and systematic discharge of surplus sludge. Mixing should be complete although too vigorous agitation results in turbidity of the effluent, destruction of the sludge floc and finely divided sludge. On the other hand, poor mixing will cause low sludge efficiency and other complications.

Failure to maintain aerobic conditions in the system brings on such unsatisfactory conditions as light, poor-settling sludge, unstable effluent and difficult plant control. Each sewage, depending on its strength, has a minimum required aeration period, which if curtailed will produce unsatisfactory effluents. Increasing the vigor of agitation will not diminish this minimum time.

Certain tests are essential for successful operation. Among those enumerated are determination of dissolved oxygen in various stages of

the treatment and estimation of the amount of sludge in circulation. This latter test is made by reading the sludge settling in 500-cc. cylinders in one hour.

Good sludge will settle rapidly in large, well defined flocs and need not be in excess of 8–10 per cent rather than from 20–25 per cent as was customary in the past. This low sludge content has been efficient in treating a strong sewage containing 0.5 to 0.75 per cent of gas liquor when at the same time aerobic conditions in the tanks are maintained and the excess sludge is removed regularly and systematically.

Reactivation of Sludge.—Sludge reactivation is desirable when treating a strong sewage; it simplifies sludge control, aids in maintaining sludge density and sludge reconditioning Proper reactivation can take place only if the percentage of sludge is within well defined limits, the percentage being lower in warm weather. Thin sludge is more efficient for mixing with raw sewage than is highly concentrated sludge.

Disposal of Activated Sludge.—Efficient disposal without nuisance is now considered more essential than the production of sludge of high fertilizer value. Specially prepared drying beds are expensive because of the large area required, dumping on low ground usually is troublesome and covering in shallow furrows results in bad odors and fly breeding. In order to reduce the volume of surplus activated sludge, the usual practice now is to return it to the preliminary sedimentation tanks and dispose of the resulting raw and activated-sludge mixture on drying beds. Such a procedure is said to aid purification of the raw sewage under certain conditions.

Sludge Digestion.—The author recommends digestion or partial digestion of activated sludge either alone or mixed with raw sludge. The removal and control of the water content of digesting sludge is of prime importance. The author has used three lagoons of a total capacity of 6 cubic feet per capita and depth of 7 feet for digestion of a mixed sludge from a plant treating over 1 m. g. d. of sewage. One lagoon is used for the primary stage of digestion, the others for the secondary or maturing stage. The digested sludge is pumped to drying beds.

Sludge drying experiments, machinery maintenance and keeping of graphical plant operation records are discussed.

The Stafford Activated Sludge Works.—The sewage is collected entirely in separate sewers to a central outfall works where it is screened and pumped to the treatment plant. About 0.5 per cent of the sewage flow consists of gas works liquor of variable strength, with an average four-hour oxygen absorption of 5500 p. p. m., and which is added through an equalizing tank to balance the flow.

The treatment plant consists of the following units:

	Total Cap., Gal.
2 Preliminary sedimentation tanks	160,000
6 Aeration tanks, 74 ft. long	454,500
6 Reactivation tanks	151,000
6 Final settlement tanks, each with four inverted pyramid hoppers	199,200
2 Sludge concentration tanks	41,000

An average reduction of 80 to 85 per cent of oxygen absorbed in 4 hours is obtained and 76 to 80 per cent of albuminoid nitrogen.

Discussion

In opening the discussion on this paper, Mr. J. A. Christian pointed out that the percentage of gas liquor in the sewage was not so critical on plant efficiency as irregular flow and particularly complete cessation of flow for considerable periods of time.

Mr. M. F. D. Windridge, commenting upon the low capacity of the preliminary sedimentation tanks, suggested that longer storage might improve treatment efficiency. He concurred with the author in the advantages of low sludge content in the aeration tanks (about 10 per cent) and noted the desirability of a standard procedure for the settleable solids test. He considered, however, that disposal of sludge on land was a satisfactory procedure if intermittent cropping was practised, otherwise the soil would become sludge sick.

Mr. S. Toon stated that at the Coventry plant experiments demonstrated the existence of an optimum air requirement for treating sewage. An increase of 15 per cent of air allowed the treatment of an additional $37\frac{1}{2}$ per cent of sewage. A fixed minimum of air is essential for keeping the sludge in suspension, for which purpose, too, design and location of air diffusion is important. Too much air was infinitely better than too little. Experience at Coventry corroborated that at Stafford in the difficulty of sludge disposal on land and the advantages of return of the excess activated sludge to the sedimentation tanks.

Mr. Percy Lamb, in discussing the air requirements, stated he had never found that an excess of air destroyed the floc and in dealing with excess trade waste or strong sewage more air was essential, consequently increased agitation. He took issue with the author concerning the necessity for sludge reactivation. Tests at the Worcester plant had demonstrated the difficulty of digesting activated sludge unless it was mixed with ordinary tank sludge. Experiments were described in which sludge dewatering is stimulated by fermentation with brewers' yeast. The fermenting process breaks down the colloidal matter, liberates the water and permits ready drying by vacuum filtration.

In closing the discussion the author answered several points raised, among which was that of the air consumption which he stated to be 1.5 to 1.75 cubic feet per gallon. J. K. HOSKINS

Combined *Versus* Separate Systems of Sewerage in Relation to Treatment

BY A. R. WARD

The Surveyor, **83**, 399–400 (April 7, 1933), and **83**, 431–2 (April 21, 1933)

This paper, read March 31, 1933, at the Manchester meeting of the Institute of Sewage Purification, in addition to discussing the subject of storm overflows and tank treatment of storm water, presents some interesting observations on the beneficial effect of dilution by rainstorms on the treatment of sewage by the activated-sludge process.

Regardless of the type of biological treatment employed for strong sewages, dilution has a beneficial effect on the process, perhaps most marked in the activated-sludge method. Thus sludge bulking quickly disappears after a relatively low rainfall, while in long dry periods this objectionable condition may persist for weeks. When bulking occurs at the author's plant (Stockton) the volume of sludge returned to the aeration units is increased and as much surplus sludge is disposed of as possible, that is, the sludge is removed from the settling tanks as quickly as possible. Furthermore the number of humus tanks in operation is reduced to a minimum to effect more rapid exchange of sludge, by which procedures the sludge is kept under control.

Another observation is that much less humus sludge is discharged during storm conditions than under normal dry weather flow, although the suspended solids in the tank effluent during storm flows are much increased. The suggested explanation is that colloidal solids are precipitated from solution under dilute conditions and the resulting tank effluent contains actually less solids capable of being thrown down in the aeration units, regardless of the increased volume treated. Oxygen absorption figures of tank effluents under normal and under storm flows are presented to show that the amount of purification to be effected by the filters and bio-aeration units is much less during storm flows than during periods of dry weather.

In the discussion of the paper, the beneficial effect of dilution by rainstorms upon sludge settling was confirmed by Mr. Lockett, who stated that the increased density then obtained was not due solely to increased mineral matter present. At such times the oxygen content of the activated sludge effluent was higher and dissolved oxygen had an effect on sludge density. He had observed that the percentage mineral matter curve and the density curve of activated sludge correlated with the rainfall curve, although not absolutely.

Considerable divergence of opinion was expressed concerning settling tank capacity, some contending that perhaps the German practice of two

hours' detention was sufficient, in opposition to other views of requirements as high as twelve hours. J. K. HOSKINS

Houghton-le-Spring Sewage Disposal

ANON

The Surveyor, **83**, 397–8 (April 7, 1933)

This recently constructed sewage treatment plant serves the urban district of Houghton-le-Spring, a coal mining area of 11,000 population. The daily dry weather flow provided for is 337,500 gallons from an estimated population of 15,000, although the present average water consumption is 16.2 gallons per capita daily. The sewage is a strong domestic one with no trade wastes.

The plant conforms to the requirements of the Ministry of Health, is located on a site of 7.73 acres and consists of:

2 Grit chambers, each 7.5 × 10 × 5 ft. deep, with screens
2 Detritus tanks, 13.5 × 10 × 5 ft. deep
2 Sedimentation tanks 100 × 26 × 7.5 ft. deep, each divided into two compartments
1 Storm water tank, 100 × 20.75 × 7.5 deep
4 Percolating filters, 94 ft. diam. by 5 ft. deep
2 Humus tanks, 47.3 × 20 × 5.5 ft. deep
$^{3}/_{4}$-Acre sludge disposal area.

A total of 12.5 ft. head is provided between the inverts of the inlet sewer and effluent drain.

Tanks.—The tanks, with the exception of the humus tanks, adjoin each other. The smaller tanks have bottoms sloping to the center, while the sedimentation and storm water tank floors slope to one end; all are provided with drainage pipes. The settled sludge from all tanks flows by gravity to a sump from which it is pumped to sludge beds. An automatic recorder, with integrator, records the flow to the sedimentation tanks.

Filters.—The filter walls are of open construction, the bottoms are of concrete upon which stoneware false tiles are laid. The filter medium is honeycomb slag of varying size. The filters are served by a dosing chamber and airlock sprinklers 94 ft. in diameter to which the sewage is supplied through a 9-inch cast iron pipe.

Costs.—The plant was constructed by direct labor. Items involved included 5300 cubic yards of clay excavation, 3370 tons of concrete and 5000 tons of slag for filters. The actual cost, including over £1000 for the purchase of coal under the site, is less than £24,000. J. K. HOSKINS

Sewage Treatment for the City of Soest in Westphalia

BY M. PRÜSS AND H. BLUNK

Tech. Gemeinde., **36**, 97, 112 (1933)

The city of Soest, population about 22,000, has a separate system of sewers. As the old treatment plant was badly overloaded and the dilution of the sewage possible in the Soestbach, 1:10, is insufficient, a new plant was necessary. In considering what type of biological purification should be used, sewage irrigation was eliminated because of its high cost and the danger of odors. Since activated sludge alone would not be satisfactory on account of its sensitiveness to change in concentration of sewage and to industrial wastes, stage treatment was chosen, with sprinkling filters as the first stage and activated sludge the second. In the first stage only partial purification takes place and the changing concentrations of the sewage and industrial wastes are equalized. Final purification is accomplished in the activated-sludge tank. This combination of sprinkling filters and activated sludge has been used for several years at the treatment plant in Holzwickede and has been satisfactory in every respect.

The plant was based on a population of 25,000 with a sewage flow of 26.4 gallons per capita per day and a maximum hourly flow equivalent to $^1/_{14}$ of the total daily flow. The settleable solids amount to 10 cc. per liter and the estimated amount of fresh solids is 884 cubic feet.

The digestion and settling tank is 49.2 feet long. The settling tank placed along each long side is 11.5 feet wide and 12.3 feet deep. The settled solids, which pass through a slot into a storage tank large enough to hold two days' supply of sludge, are forced into the digestion tank. The skimmings from the settling tank are forced directly into the digestion tank. The digestion chamber, which has a capacity of 26,400 cubic feet, is a single tank 49.2 feet long, 19.7 feet wide and 36 feet deep. The bottom slope is 1:1 so that the sludge slides to the lowest point for removal. Two screw pumps, provided for vertical sludge circulation, draw the sludge from the bottom and sprinkle it over the entire surface. The direction of circulation may be changed so that the floating solids are sucked down and forced into the bottom of the tank. Since the temperature of the incoming fresh solids varies between 46.4° and 59° F., artificial heat is necessary to maintain a temperature of 68° F. The heating coils are placed not in the sludge but in the sludge liquor, an arrangement which can be successfully carried out only when the whole contents of the tank are circulated.

The size of the sprinkling filter depends upon the amount and concentration of the sewage. With a sewage flow of 26.4 gallons per capita per day a load of 7.48 gallons to 1.4–1.5 cubic feet of filter material is customary in

Germany. In order to obtain the partial purification desired in this case, a load of 7.48 gallons per 0.85 cubic foot of material will be used. There are three sprinkling filters, each 54.2 feet in diameter, 11.8 feet deep and containing 24,700 cubic feet of material. Scoriaceous lava was chosen as filter material since it has an extremely rough surface and is not easily decomposed by weather. Three different sizes of lava were used. In the lowest layer was placed material 3.2 to 5.9 inches in size, to a depth of 1.8 feet. The next layer, of 1.2 to 1.6 inches material, is about 6.9 feet in depth and the top layer, size 1.6 to 3.2 inches, 3.28 feet in depth.

Because of unfavorable ground conditions, a combination activated sludge and secondary settling tank was built in order to utilize the great depth which was necessary. Superficially it looks like an Imhoff tank. The aeration tank has a diameter of 25.0 feet and a total depth of 39.4 feet. The upper and lower part are cone-shaped. The sewage is added at the top. The aeration tank is connected with the settling tank half way down, by a slot through which the liquor passes from the aeration chamber to the settling tank. The return sludge flows back into the aeration tank and the effluent is removed at the top through movable pipes. Three centrifugal pumps are provided for pumping the clarified sewage to the sprinkling filter and three air compressors are used to furnish air for aeration of the sewage and for pumping the excess sludge. Two compressors, with a capacity of 70,600 cubic feet per hour, are used during the day and one of 2120 cubic feet per hour capacity is used during the night. A 33 hp. gas motor, which drives a generator, furnishes the electrical power for 16 hours' operation. Only the largest centrifugal pump, which is seldom used, must be operated by power from the municipal electric system. The electricity needed for operating the compressors at night is purchased.

Heat is required for heating the machine house and the sludge digestion tank and as protection against frost for the gas meters. The heat required is as follows:

	28° F. B. t. u.	5° F. B. t. u.
Digestion tank	3,400,000	4,030,000
Machine house	1,310,000	1,710,000
Gas meters	528,000	1,090,000
Total	5,238,000	6,830,000

In sixteen operating hours there are 1,900,000 B. t. u. available from the gas motor. This is sufficient for heating the digestion tank in summer, but only for heating the machine house and for protection of the gas meters in the winter, and in the coldest weather only for heating the machine house. A gas-heated boiler is provided for the other heating needs. Since in this system 1 cubic foot of gas yields about 562 B. t. u., 9180 cubic feet of gas are necessary for heating on the coldest day. The gas motor uses 14.8 cubic

feet per horsepower per hour or 8300 cubic feet per day. For operation of both plants in the coldest weather about 17,650 cubic feet of gas are needed, which is about 0.88 cubic foot per capita per day for 20,000 inhabitants. In case the amount of gas is not sufficient, complete heating is not done in the coldest weather.

With a temperature difference of 54° F. a heating surface of 129 square feet is required in the digestion tank. Using pipe 2.26 to 2.5 inches in diameter, a length of 197 feet is required. These pipes are arranged in coils and each pipe can be removed for cleaning, if necessary, without disturbing operation. This is a great advantage over the fixed type on the side walls or the bottom.

About 370 gallons of hot water are circulated each hour and a pump of 660 gallons capacity is provided for this purpose.

The operation of the plant is extremely simple, requiring only one attendant. The raw sewage has the following composition:

Physical properties: very turbid, grayish white, solids finely divided, odor like fresh sewage		
Reaction (litmus): weakly alkaline		
Clarity, unfiltered: 1.5 cm.		
filtered: 3.5 cm.		
Settleable solids after 2 hours: 9.8 cm. per liter		
Stability, unfiltered: septic within 24 hours		
filtered: septic in 3 days		
Suspended solids:	mineral	66 p. p. m.
	organic	145 p. p. m.
	Total	211 p. p. m.
Soluble matter:	mineral	780 p. p. m.
	organic	336 p. p. m.
	Total	1116 p. p. m.
Nitrogen:	ammonia	25 p. p. m.
	organic nitrogen	16 p. p. m.
Oxygen consumed ($KMnO_4$)		371 p. p. m.

Only a few grab samples of effluent have been analyzed and an average analysis is shown below.

	Effluent from Mechanical Treatment Plant	Effluent from Activated-Sludge Plant
Suspended solids	180 p. p. m.	Not weighable
Mineral	36	Not weighable
Organic	144	Not weighable
Soluble matter—organic	260	130 p. p. m.
Nitrogen		
As nitrates	0	18
As nitrites	0	
As organic nitrogen	17	1
Oxygen consumed ($KMnO_4$)	371	97

The effluent from the secondary settling tank was always stable. An average of 300 determinations showed that the raw sewage, after 2 hours' settling, contained 10 cm. per liter of settleable solids, whereas the mechanically clarified sewage contained 0.1 cm. per liter.

The pH of the raw solids is about 6.6 or lower. Lime, circulation of sludge and heating were used to start the digestion tanks. The digested sludge has a pH of 7.4 to 7.6. The amount of fresh solids added daily has averaged about 1060 cubic feet. This unusually large amount results from the highly concentrated sewage. About 353 cubic feet of sludge from the biological plant are added daily to the fresh solids, an extremely small amount as compared with that from an activated-sludge plant, since the sludge from the sprinkling filter contains less water than does the activated sludge. The sprinkling filter sludge retains its structure in passing through the aeration tanks so that less sludge needs to be handled and heated in the digestion tank. The digested sludge is used partly for agricultural purposes and partly for fill. The sprinkling filter started very quickly and a good effluent was obtained in three weeks. There has been no odor nuisance and although *Psychoda* have appeared in the immediate vicinity of the sprinkling filter, they have not caused trouble. The plant was put into operation in July, 1932. G. P. EDWARDS

Use of Gas from Municipal Treatment Plants as Motive Power for Trucks

BY ING. BEINHAUER

Gesundh. Ing., **56**, 209 (1933)

Because of the high cost of motor fuel in Germany an attempt has been made to use compressed methane gas as a source of motive power. In the Ruhr district investigations on the use of coke oven gas have shown that methane gas can be used successfully for operation of trucks without making any change in the motor. The gas is compressed to 150 atmospheres in steel cylinders, which are connected in batteries of five or six. For use, the pressure is reduced and the gas introduced through a specially built mixing valve directly to the motor. The Concordia Bergbau A.-G. has operated a 4.5 ton truck continuously for more than a year with methane gas and an examination of the motor showed that there were no deposits on the spark plugs, valves or cylinder walls. In Oberhausen it was determined that 120 cubic feet of methane gives the same power as one gallon of benzol. The disadvantages of methane gas operation are the necessity of carrying the fairly high dead weight of the gas cylinders and the fact that

the operating radius is limited to short hauls. Chrome nickel steel light weight cylinders with capacities of 350, 700 and 1050 cubic feet have been developed in France and the use of methane as motor fuel has been successful in the cities of Lille, Valenciennes and Boulogne. The cost of apparatus for use of methane gas in a 5-ton truck, consisting of ten cylinders, each with a capacity of 350 cubic feet (effective radius about 125 miles) and with reducing and mixing valves was estimated to be about $425.00. The average composition of the gases from the digestion tanks at Halle is as follows:

	Per Cent
Methane	68.55
Carbon Dioxide	29.74
Nitrogen	1.53
Hydrogen Sulphide	0.10
Oxygen	0.08

The heating value averages about 730 B. t. u. per cubic foot. The carbon dioxide and hydrogen sulphide can be removed at a cost of about one cent per 28 cubic feet of gas and the heat value is thereby increased to about 800 B. t. u. At the present time, the digestion tanks at Halle yield about 70,600 cubic feet of gas per day, which is sold for 21.2 cents per thousand cubic feet. The compressor plant consists of a horizontal four cycle, one cylinder gas motor of 20 hp. which is operated with unpurified methane gas. Coupled with it is a stationary three-stage high pressure compressor with a suction capacity of about 1400 cubic feet per hour. The total cost of the plant is about $1450.00. The ordinary German 40-liter cylinder holds about 210 cubic feet of gas and the cylinder weight amounts to about 0.69 to 0.81 pound per cubic foot of gas. A 6-cylinder truck of 100 hp. requires, with heavy loads, about 14.5 gallons of benzol per 62 miles or 1765 cubic feet of methane. Therefore eight cylinders, with a total weight of 1265 pounds, must be carried along. The French chrome nickel steel cylinders, however, weigh only 0.34 pound per cubic foot of gas. For a 5-ton truck with an effective radius of 62 miles, 1765 cubic feet of gas must be carried along or with five cylinders, each with a capacity of 353 cubic feet, the total cylinder weight is 605 pounds or about 5 per cent of the truck load. Allowing for interest, amortization and operating costs, the cost of 35.3 cubic feet of gas is about 6 cents. The methane gas is on an average at least 50 per cent cheaper than liquid fuel. Any excess compressed gas can be sold. The trucks need not be limited to an effective radius of 62 miles since, after the gas is exhausted, liquid fuel can be used. The use of methane gas in trucks is possible and economical.

G. P. EDWARDS

Oxygen and Carbon Dioxide in Sprinkling Filters

BY H. BACH

Gesundh. Ing., **56**, 189 (1933)

Not only sufficient oxygen, but also removal of the carbon dioxide formed, is necessary in the biological treatment of sewage, since the carbon dioxide is poisonous to the bacteria. Pettenkofer has determined that the presence of more than 0.1 per cent carbon dioxide by volume in the air is injurious to the health of man. Although there are no exact data showing the carbon dioxide concentration which is poisonous to the bacteria of sprinkling filters, it has been assumed that a marked increase of the carbon dioxide content of the air of the sprinkling filter retards the activity of the bacteria. The carbon dioxide content of pure, that is, unbreathed, air amounts to 0.025 to 0.03 per cent and it is assumed in the following calculations that the content of 0.4 per cent carbon dioxide would greatly decrease the activity of the bacteria and that the carbon dioxide content in the sprinkling filter air should not be allowed to rise higher than 0.2 per cent. The loading of a sprinkling filter depends upon the organic content of the sewage and to a certain degree upon the amount of air added and the amount of carbon dioxide present in the filter. In the filter bed there are about 30 per cent voids or in 35 cubic feet of filter material there would be about 10.5 cubic feet of air. If it is assumed that the average B. O. D. of sewage is 150 p. p. m. and that 14.5 gallons are added per hour to every 35.3 cubic feet of filter material, then 8.3 grams of oxygen, which is the amount contained in 0.8 cubic foot air, are required. If all of the 8.3 grams of oxygen are converted by the bacteria to carbon dioxide, 22.8 grams would result, giving a concentration of four per cent carbon dioxide by volume, in the air or more than ten times as much as that mentioned as the danger limit for long time operation. The amount of carbon dioxide dissolved by the sewage is relatively small and about 6 cubic feet of air per hour must be added to each cubic foot of the sprinkling filter to maintain a carbon dioxide concentration of about 0.2 per cent by volume. The filter must be constructed so that not only addition of oxygen but the removal of carbon dioxide to the required degree occurs. If the sprinkling filter is enclosed by walls, air must be pumped up countercurrent to the sewage. In the winter time, to save fuel while maintaining an equal temperature, it is advantageous to add only as much fresh air as is required to hold the carbon dioxide concentration low. The most economical method would be to pass the gas through milk of lime or caustic soda to remove the carbon dioxide and recirculate the purified air through the filter.

G. P. EDWARDS

Second Annual Report of the Aurora Sanitary District for the Year 1932*

BY WALTER S. SPERRY

During 1932 the Aurora Sewage Treatment Plant treated 2636 million gallons of sewage, enough to fill a canal 40 feet wide, 10 feet deep and 166 miles long, or from Aurora to Iowa City, Iowa. The screenings and grit would fill 309 1-yard dump cars, and the gas produced would be sufficient to supply 400 Aurora homes for a year, or to fill the local holder over six times. Thus Mr. Sperry shows himself adept at an art too much neglected by sewage works superintendents, namely, that of visualizing the operation of the plant for the layman and of convincing Mr. and Mrs. Public that they are getting full value for their tax money. Much thought and effort were expended during this period to beautify the grounds with trees and shrubbery, and of the interiors of the building with paint. A cover was placed over the screenings box to avoid offending the visitor with its unsightliness.

A change was made in the storm overflow so that the excess flow passed through the screens and detritor before bypassing to the river. A severe fire occurred in the screen house, caused by oil and gasoline which had been removed from the clarifiers to the grease skimming box, and did considerable superficial damage. As a result of this fire this portion of the building was fire-proofed, and the plant was supplied with fire extinguishers. A thorough canvass was made of all places which might discharge inflammable material.

Several improvements were made during the year. The overflow from the digestion tanks, which formerly discharged to the clarifiers, was changed to empty into the incoming sewage main directly, thus simplifying operation when a clarifier was out of service. An interesting method was adopted to get proportional samples. Sampling cups with volumes corresponding to the numbers between 5 and 16 were provided, the sample taken using the cup number equal to the meter reading in m. g. d. The policy of adding flushing water to the sewer as a means of odor control was continued this year with gratifying results. No complaints were received from odors during the year, and the H_2S in the incoming sewage was kept well below 1.0 p. p. m.

Low removals of suspended solids in the clarifiers led to an investigation early in 1932, which revealed that the four clarifiers were receiving 23, 33, 27 and 17 per cent of the total flow, respectively, and that there was considerable short circuiting in the individual units. These faults were corrected by resetting the weirs and installing wooden baffles, placed so as to destroy the inlet velocity. The operation was then checked by a method

* Published only in mimeographed form.

suggested by Dr. Fischer of the Dorr Company. A garbage can was filled with the incoming sewage, and after a time corresponding to about 80 per cent of the theoretical detention period of the clarifier tank, a sample was taken of the surface water of the can. The ratio of the per cent removal of suspended matter in the can to that in the clarifier gave the "efficiency." This efficiency was between 92.8 and 100 per cent with both heavy and light flows. The motion of the collector arms did not interfere with sedimentation. The marked improvement in operation of the clarifers due to these changes is shown below:

	Period	Per Cent Removal Susp. Solids	Solids Removed Lb./Day	Gas Produced Cu. Ft./Day
Before changes	1/1/31 to 4/1/32	39.4	3150	27,420
After changes	4/1/32 to 1/1/33	60.3	4410	36,700

In the winter, only two clarifiers will be needed now, without sacrifice in effluent quality. This will save $15 to $20 per month on the power bill.

The filters were in operation from May 21 to November 17 only, as during the remainder of the year the oxygen content of the river water was sufficient to take care of settled sewage. This saved the cost of operating the pumps during the winter.

The sludge beds were cleaned only twice a year, in May and August. The sludge removed had a moisture content of only 5.5 per cent. After supplying the city parks, the remainder was sold at 50 cents per cu. yd.

The monthly results of operation are given in a form to be easily understood by the layman. The totals only are given for sewage treated, grit, scum grease and sludge removed and gas produced. The total monthly oxygen demand of the raw sewage and plant effluent and the dissolved oxygen available in the Fox River are given in tons. The removals of oxygen demand are rather low, 20 to 25 per cent in the winter with settling only, and 72 to 80 per cent in the summer with the filters operating; but the oxygen demand of the effluent is well below the oxygen content of the river water at all times.

Monthly averages of the analyses of the gas produced are given with a view to possible future power development. The methane content is very constant, varying only between 57.9 and 63.1 per cent of the total. The yearly average of the analyses were: CO_2, 31.2 per cent; O, 0.6 per cent; H, 3.6 per cent; CO, 0.7 per cent; CH_4, 61.0 per cent and N, 2.9 per cent. H_2S varied between 186 and 756 p. p. m. with an average of 443 p. p. m. for the monthly averages. The average B. t. u. of the gas was; gross 628 and net 594 per cu. ft. Gas produced varied between 691,000 and 1,432,000 cu. ft. per month. Much of this variation was due to changes in the settling tanks described above.

The digesters were operated at 88° F.

The digestion of volatile matter based upon the difference between the volatile matters of the sludges as added to and removed from the tanks was 67.1 per cent. Based upon the weight of the gas produced, 80.7 per cent of the volatile matter was digested, equal to 1.25 pounds of gas per pound of volatile matter destroyed.

Samples taken of the Fox River water at six stations below the plant showed a minimum D. O. in the winter of 4.0 p. p. m. and in the summer of 5.2 p. p. m.

RALPH J. BUSHEE

Fourth Report, Metropolitan Drainage Commission, Minneapolis and St. Paul, 1931 and 1932

BY JAMES A. CHILDS

Historical Review.—The area with which the commission is concerned contains nearly 135,000 acres, with an estimated population of 775,000 in 1927. The sewered population was 685,000, and a total of 100 m. g. d. of sewage and packing-house wastes is discharged to the Mississippi River through 84 main and relief outlets. Based on the oxygen demand, this sewage is equivalent to that of a population of 1,300,000 persons. Except during high water a condition of public nuisance exists between the Twin Cities and the influx of the St. Croix River at Prescott. This has resulted in a depreciation of real estate values, a loss to the fishing industry and a health hazard.

The commission made a study of remedial measures and outlined, in general terms, tentative projects, a method of cost apportionment and a policy for the organization of a sanitary district. Bills were presented in the 1931 session of the State Legislature, and one was passed and later vetoed by the governor. This bill provided that the cost of all of the work for construction, operation and maintenance should be apportioned among the various municipalities according to their assessed valuation. The opponents of this bill argued that too great a share of the cost of treatment of the wastes from the stock-yard districts of South St. Paul and Newport would be borne by taxpayers of the other communities involved and advocated a volume basis of cost apportionment for maintenance and operation charges of the treatment works. The proponents of the assessed valuation method argued that such a cost distribution would place a greater burden on the large waste producing industries of Newport and South St. Paul than on similar industries in Minneapolis and St. Paul.

A joint committee appointed from the officials and executives of Minneapolis and St. Paul has held meetings and has tentatively agreed upon a bill which would be acceptable to both communities. Partly as a measure

of unemployment relief, Minneapolis has expended $100,000 in the construction of a portion of its intercepting sewer.

Mississippi River Investigation.—The low water of 1929 and 1930 continued through 1931 and 1932, with the average monthly flow of the river exceeding 5000 second feet for only one month in 1931 and four months in 1932. The reservoirs at the headwaters of the Mississippi were drawn down so that only 2,080,000 cu ft. were available for release at the beginning of 1931. After a hearing of the conflicting claims of the property owners on the lakes, who protested against the violent fluctuations of the water level, the cities of Minneapolis and St. Paul, who wished their water supplies protected, and the commission, who stated that a saving of $900,000 a year could be effected in sewage treatment costs by 1940 with a suitable operation of the reservoir discharge, the Secretary of War issued an order establishing a maximum storage of 91.5 M cu. ft. and a minimum storage of 28.1 M cu. ft. in these reservoirs and permitting the exercise of discretion in the discharge of water for emergency use.

Effect of Hastings Dam.—Since the completion of the Hastings Dam the foul condition of the river above the site of the dam has been more noticeable. The low point of the dissolved oxygen curve is approximately midway between St. Paul and this dam. During four months of 1932 the oxygen was entirely or nearly entirely exhausted in this stretch. Samples taken from the river bed in October of 1931 and a year later showed an increase in volatile matter, indicating sludge deposits. The increase was from 1.0 per cent volatile matter in 1931 to 5.8 per cent in 1932.

The possibility of wind movement causing floating material to drift upstream from Newport and South St. Paul, thus offsetting partly the improvement of the river resulting from the proposed Twin City sewage treatment works, was investigated. The danger was found to be remote.

The fall caused by the dam results in a considerable increase in the dissolved oxygen content of the water in the river. A table is given showing the D. O. above and below the dam, the water temperature and the difference in head above and below the dam. It is to be expected the increase in D. O. is greater with the greater heads and when the water above the dam contains less D. O. There has been a noticeable improvement in the conditions through Lake Pepin in the past two years, as shown by the somewhat higher dissolved oxygen content. Influencing factors are: (*a*) settling of suspended matter in the pool above the dam, (*b*) longer flowing time allowing re-aeration, (*c*) aeration caused by flowing over the dam; (*d*) mild, open winters with little ice covering, allowing more surface re-aeration. It is to be expected, however, that the oxygen demand of the increasing sludge deposits above the dam, will tend to offset this improvement in the future.

The routine collection of samples from the seventeen sampling points

was continued throughout 1931 and 1932, and new data obtained on the effect of the extremely low water, decrease in industrial load, settling and aeration caused by Hastings Dam and increased re-aeration in winter due to absence of ice cover. These results are important as it is planned to vary the degree of treatment to suit the condition of the river. There was an increase in the D. O. of the entering river water at Camden during this period. This may be caused by a more luxuriant growth of plankton organisms.

The Project.—After making further studies and re-designs, three of the typical projects were discussed. They are: (1) Project I-10 with a combined activated-sludge plant for Minneapolis and St. Paul at Pigs Eye Lake; (2) Project Da—a treatment plant at Pike Island for Minneapolis and the western part of St. Paul and a second plant at Pigs Eye Lake for the eastern part of St. Paul. The plant at Pike Island would be sedimentation and partial secondary treatment by activated sludge in the earlier years, and sedimentation only at Pigs Eye Lake. The sludge from the Pike Island Plant would be pumped to Pigs Eye Lake and disposed of there. (3) Project T provides for separate and independent systems for Minneapolis and St. Paul, with an activated-sludge plant at Ft. Snelling Military Reservation for Minneapolis and an activated-sludge plant at Pigs Eye Lake for St. Paul.

A comparison of the first costs and annual charges for the various projects as of 1945 is as follows:

	Project		
	I-10	T	Da
Total construction cost	$16,315,000	17,195,000	13,495,000
Operation and maintenance costs	565,000	705,000	610,000
Total annual charges	1,625,000	1,820,000	1,485,000

The Commission strangely favors the I-10 project even though it is somewhat more costly than the Da project, as it would provide a cleaner river through St. Paul and the obvious advantage of locating all of the treatment in one place which is isolated and provides room for expansion. Project T, of course, would have all of the disadvantages of project Da and in addition would be considerably more costly than either of the other two projects.

In figuring the annual charges, $6\frac{1}{2}$ per cent of the total cost of the project is used for fixed charges. This is based upon the cost to retire 30-year serial bonds rather than on the actual depreciation of the units. The actual annual cost would be less than this as it is planned that the construction would be spread over a period of about nine years, during which there would be no operating costs and a much lower interest cost.

Project I-10 is a redesign of Project I-5 of the 1929–30 Report with a more advantageous location of sewers, which would reduce the amount of

sewage to be pumped from 18 per cent to 1.8 per cent of the total, reduce the first costs by $510,000, decrease the number of river crossings from five to two, and would provide a gravity sewer in place of the long pressure outfall. The treatment plant would consist of screen and grit chambers, preliminary settling tanks, aeration tanks, sludge disposal facilities and the necessary buildings. Of the total cost of Project I-10 as of 1945, the estimated cost of the sewers would be $10,810,000 and of the treatment plant $5,395,000, based on an assumed *Engineering News-Record* cost index of 200. The Commission recommends that the cities of St. Paul and Minneapolis each build and maintain those sewers and pumping stations used exclusively by them, that the cost of construction of the sewers used jointly and of the sewage treatment works be apportioned according to the assessed valuations of the two cities, and that the operating and maintenance charges be apportioned on the basis of the annual sewage volume from the municipalities.

South St. Paul and Newport are not included in the project but could easily come in later, if desirable, by making additions to the treatment works. The effect of recent economies in the packing industries tending to a reduction of wastes needs to be studied.

A tentative construction program is given spreading the construction over the period of 1933 to 1941, inclusive. RALPH J. BUSHEE

Eighteenth Annual Report, Bureau of Sewage Disposal, Year 1932, Schenectady, New York

BY MORRIS M. COHN

The operation of an overloaded 20-year old sewage treatment plant, with the production of an effluent comparable with the best from more modern works, would mean a full and busy year for most plant operators. In addition to this, the suggestion of a so-called "Bureau of Municipal Research" that the sewage plant be closed to save funds had been averted only by the coöperation of the State Board of Health. A strike of the plant operators had made it necessary to break in an entirely new force, and when the position of Sanitary Chemist was abolished the necessary analytical sewage work and special investigations were carried on with the help of only a laboratory assistant on two-thirds time. However, for Mr. Cohn this is only a part-time job. Half of his time he devotes to "smoke abatement, swimming pool and wading pool sanitation, rodent eradication and investigation of water problems . . . supervision of material testing and technical control of asphalt patching contracts." One wonders why the city does not have Mr. Cohn sleep in the station house, to come sliding down the

pole, booted and helmeted, to aid the fire department on the night alarms.*

The interceptors were overloaded and it was necessary to divert sewage during storms at two places on the interceptor system. The sewage treated daily varied between 4.0 and 10.2 m. g. with a yearly average of 8.41 m. g. d. This is about equal to the 1931 figure, as the decrease in industrial load was offset by increased infiltration, caused by the heavy rainfall experienced during the year.

The $1^1/_4$ inch spaced rack screens removed a total of 172 cu. yd. of trash, equal to 1.51 cu. ft. per million gallons. The screenings were disposed of very successfully during the summer by shallow plowing. Disposal by shallow trenching in the winter was rather troublesome due to the high level of the ground water caused by the canal.

The operating difficulties of the Imhoff tanks, which are characteristic of this plant, were somewhat mitigated during this period. By persistent chaining and squeezing, the slopes of the baffle walls were kept free of sludge and the usual reduction of efficiency caused by gas lifted "islands" of sludge in the settling compartments did not occur. Also there was less trouble than usual due to the scum-forming characteristics of sewage solids. After a thorough hosing of the gas vents in April, it was not necessary to resort to much hosing until the end of July. From July to December it was necessary to resort to frequent hosing in order to get the solids to the sludge drawoffs. Foaming occurred in May and was controlled by removing the sludge from the affected tanks. It could not be proved that the foaming was accompanied by a lowering of the pH value in the contents of the sludge compartment. The sludge is usually slightly on the acid side of the scale.

The flow through the tanks was reversed frequently and it was arranged to keep the direction of flow against that of the wind as much as possible, in order to reduce short-circuiting in the tanks to a minimum. A movable wire screen was placed at the outlet of the tank to catch the floating solids, which were put in the gas vents. The inlet gates were clogged frequently, stoppages averaging about fifty a month.

The results obtained from the Imhoff tanks were gratifying. The removal of settleable solids for the year averaged 87.9 per cent, with a minimum monthly average of 82.7 per cent. The removal of suspended solids averaged 75.8 per cent, with a minimum monthly average of 68.1 per cent.

From May to November 13, 139 cu. yd. of sludge were removed from the Imhoff tanks. In general, the sludge was of good quality, although some of the sludge removed after hosing the gas vents near the end of the season was apparently not fully digested. Of this sludge 11,189 cu. yd.

EDITOR'S NOTE: The abstractor neglected to mention Mr. Cohn's further activities as editor of the "Grit Chamber" in *Municipal Sanitation* and as editor of the New York State Sewage Works Association.

were placed on the drying beds and the remainder was pumped into a lagoon in the fall, to clear out the tanks for the winter. The sludge drawn to the beds averaged 94.4 per cent moisture, and ten beds were filled 101 times or an average of 10.1 dryings per bed for the season. The beds were filled to a depth of about ten inches, and the dried cake was $3^1/_2$ inches thick with a moisture content of about 65 per cent.

All of the dried sludge was sold at from 25 cents to 75 cents a load, depending on size.

The three acres of trickling filters performed very satisfactorily, despite the fact that high water in the Mohawk River submerged the underdrains 71 per cent of the time and at times completely submerged the filters. The average reduction of the B. O. D. in the filters was 83 per cent, and the over-all reduction of the plant was 88 per cent. The filters showed no tendency to unload at any time, and pooling was completely absent throughout the year.

For fly control, in addition to fly singeing, the beds were flooded at intervals of once a week during the hot weather, and once a fortnight during the cooler fall months. The flooding period varied between 18 and 24 hours. Flooding was carried out when the larvae counts reached a certain density.

The careful operation of the tanks resulted in keeping the nozzle clogging to a minimum. Stoppages averaged 13 per m. g.; or 8.3 per cent of the nozzles in service daily. A heavy gelatinous film formed over the nozzle dome and spindle, and interfered with the distribution. During the winter the nozzles were washed three times to remove this film. In the summer, three short rest periods resulted in drying and removal of this film. In order to control odors, the plant influent was given 4.0 p. p. m. of chlorine and the tank effluent was chlorinated during the summer when the odor and wind direction made this necessary.

Some yearly average operating results are given below in p. p. m.:

	Crude Sewage	Tank Effluent	Final Effluent
Free Ammonia N	13.7	15.3	6.4
Nitrate N	...	..	5.9
Suspended Solids	161	39	29
B. O. D.	118	83	14

The cost of treatment per million gallons, not including depreciation, was: pumping $3.58, labor $4.47, other costs $2.73. In "other costs" there is an item of $0.82 for taxes.

A sanitary survey of the river made by two graduate students of Union College brought out the fact that the sludge deposits caused by the plant shutdown in 1920 still persisted in an active state of decomposition.

The report is an interesting account of what excellent results can be obtained by good operation with an overloaded plant built according to the best practice of twenty years ago. RALPH J. BUSHEE

Power Production from Sludge Gas at Springfield, Illinois

BY W. B. WALRAVEN

Water Works and Sewerage, **80**, 151 (1933)

Recently a gas engine and heat recovery units have been installed in the sewage treatment plant of the Springfield Sanitary District. Test results indicate that 81.7 per cent of the heat value of the gas was recovered as useful work or went into the digestion tank heating system. A distribution of the heating units showed that 21 per cent was returned as work, 42.8 per cent was recovered from the engine water jacket and 17.9 per cent in the exhaust heater. The Clark Brothers vertical gas engine has six cylinders (9 by 11 inches) and is rated at 177 indicated horse power at 514 r. p. m. with 65 pounds of mean effective pressure. This unit drives a Connersville, positive-displacement, direct-connected blower (previously electrically driven), designed to deliver 3300 cubic feet of air per minute against a discharge pressure of 8.5 pounds per square inch. The engine cooling water and the exhaust gases pass through a No. 5 Paracoil heater. Circulation is provided by centrifugal pumps which force the water through the water jacket to the heater and thence through heating coils within the sludge digestion tank where the excess heat is absorbed, before the water returns to the engine. It is estimated that the average annual saving in current will be in the vicinity of $5742.00.

G. P. EDWARDS

A Study of Ferric Chloride Treatment of Sewage at Grand Rapids, Michigan

BY E. F. ELDRIDGE AND N. G. DAMOOSE

Water Works and Sewerage, **80**, 207 (1933)

Oxygen conditions in the stream receiving the effluent from the Grand Rapids sewage treatment works are such, at certain periods of the year, that additional removal of solids and oxygen demanding materials is necessary as a safety measure. The cost of providing secondary treatment for

this short period annually does not seem warranted. An additional removal of 20 to 25 per cent of the suspended solids and B. O. D. at such periods would often be all that would be necessary to maintain satisfactory conditions in the stream. Experiments using ferric chloride to increase solids removal were made on one of the 70-foot square Dorr clarifiers. The doses of ferric chloride were 3, 5, 7 and 10 p. p. m. The ferric chloride and sewage were well mixed in the air agitated conduits but the detention period was not long enough to effect flocculation. Flocculation took place in the settling tanks and would not be equivalent to that obtained in coagulation basins or in flocculators. The application of ferric chloride produced an increase in the removal of suspended solids and a reduction in the B. O. D. and chlorine demand. In all cases, except with 3 p. p. m. ferric chloride, a greater volume of sludge was removed from the treated tank and in all but two cases, the sludge was higher in solids. After subtracting the weight of anhydrous ferric oxide, all of which was assumed to be present in the dried sludge, the net increase in dry solids from the treated sewage was about 17.8 per cent greater than from the untreated sewage, over a period of eight days. Gas production in the digesters receiving the treated sludge was higher than that from the untreated due to the larger quantity of solids digested. Because of the low solids content of the Grand Rapids sewage during most of the time of the tests, the results may not be indicative of what may be possible with a stronger sewage. The results indicated that greater removals could be expected when the solids content was high.

G. P. EDWARDS

Chlorination at Downers Grove, Illinois, Helps Solve Sewage Works Odor and Stream Pollution Problems

BY H. F. FERGUSON AND W. H. WISELY

Water Works and Sewerage, **80**, 200 (1933)

An increase in population of the Downers Grove Sanitary District from 3500 to nearly 12,000 in about six years made the sewage treatment works built in 1922 very inadequate and resulted in objectionable pollution of St. Joseph Creek with many complaints of odors by property owners for several miles down-stream. The original treatment works, comprising an Imhoff tank, sprinkling filter and secondary settling tank, were supplemented by Imhoff tanks equipped for gas collection, sludge drying beds, combination screenings incinerator and waste gas burner and an administration building. The sewage flowing to the old Imhoff tank was dosed with about 10 p. p. m. of chlorine at the screen chamber. The sewage

flowing to the new Imhoff tanks was dosed with about 15 p. p. m. chlorine at the diversion manhole before sedimentation and about 9 p. p. m. at the new tank effluent manhole just before discharge to the creek. These dosages gave chlorine residuals of 0.3 to 0.6 p. p. m. at the old Imhoff tank inlet, 0.06 to 0.4 p. p. m. at the new tank inlet, 0.01 to 0.2 p. p. m. at the old tank outlet weir and 0.2 to 0.7 p. p. m. at the new tank outlet to the creek. From the standpoint of prevention of odors at the plant and vicinity, the chlorination was very successful and dissolved oxygen determinations made during chlorination demonstrated an appreciable improvement in the condition of St. Joseph Creek. About one-fourth mile below the sewage treatment works, St. Joseph Creek consistently showed a dissolved oxygen content of over 3.5 p. p. m. with an average chlorine residual of about 0.3 p. p. m. The stream banks and bottom were kept free of sewage fungus growths during chlorination but upon discontinuance of the use of chlorine in October, the growths returned and became very profuse later in the winter. During 1932, chlorine was used for 204 days at a chlorine cost of $4.41 per million gallons of all sewage treated.

G. P. EDWARDS

A New Method of Concentrating Activated Sludge

BY R. F. GOUDEY AND S. M. BENNETT

Water Works and Sewerage, **80**, 179 (1933)

The process depends upon withdrawal of the excess activated sludge in the form of mixed sewage and sludge from the main aeration tanks rather than from the final settling tanks, as is usually done. The mixture is allowed to settle in a continuously operated clarifier, designed on a basis of 600 gallons per square foot of surface area per day. The inlet to the clarifier is at the side and the influent enters at the bottom. The overflow liquor from this excess sludge clarifier is equally as good as the final effluent from the conventional final clarifiers and is mixed with the latter. A chlorine dose of about 25 pounds per million gallons sewage treated is applied to the top water of the clarifier to maintain a residual of 1.0 p. p. m. of chlorine in the liquid above the sludge. This residual which aids in maintaining adequate dissolved oxygen in the tank is sufficient to disinfect the final effluent from the entire plant. The thick concentrated sludge is pumped once daily from the thickening tank. The average water content of the sludge after nine months' operation is 94.80 per cent.

G. P. EDWARDS

Dried Sludge for Fertilizer

BY J. B. NEALY

Municipal Sanitation, **4**, 49 (Feb., 1933)

The City of Houston, Texas, is disposing of the sludge from its activated-sludge plants by pressing on vacuum filter of the American type and drying. The finished product is sold as fertilizer under the trade name Hu-actinite.

The sludge is dewatered to about 80 per cent on the filter from where it is carried on belt conveyors to storage bins. From the bins it is fed into two rotating gas-fired driers similar to those used in cement mills. Here it is dried at a temperature of 1600° F. for two hours and discharged with a moisture content of about 5 per cent. The dry product is screened, graded and either stored in bins or loaded directly into railroad cars.

Experience in the costs of constructing and operating this plant has been such that it is recommended that intercepting sewers be laid to concentrate the sewage of the remainder of the city in another large activated-sludge plant and press and dry the sludge as described above. This sewage is at present being treated in six small plants. The sludge is dried on sand beds.

E. HURWITZ

Effect of Ferric Chloride Shown by Sewage Plant Tests

BY HARVEY O. BANKS

Municipal Sanitation, **4**, 48 (Feb., 1933)

An experimental sewage plant of 3600 g. p. d. capacity was operated at Palo Alto, California, to determine the efficacy of ferric chloride as a coagulant for sewage colloids and solids. The plant was so constructed that the spent coagulant could be recovered, regenerated with chlorine and used again. It was found, however, that due to an accumulation of organic matter on the surfaces of the particles, the specific gravity was decreased to a point where they would no longer settle. Furthermore, with each successive regeneration the chlorine demand was increased. Consequently this feature was abandoned. It was noted, however, that small amounts of ferric chloride produce a well clarified effluent and further experiments were made to determine the degree of removal of suspended matter and B. O. D. which might be attained with ferric chloride by plain coagulation. The results of these experiments showed a suspended solids removal of 80 to 85 per cent and a B. O. D. reduction of 65 to 70 per cent. The effluent was somewhat opalescent but entirely

free from suspended particles. The volume of the sludge formed was 45 per cent more than by plain sedimentation. The moisture content was 0.5 per cent higher. The dry solids p. m. g. removed after correcting for ferric oxide formed was 25 per cent more than by plain sedimentation. The sludge was amenable to filtration on a vacuum filter. Cost of chemicals p. m. g. sewage is given as:

Ferric chloride	$5.35
Chlorine	3.00
Chemicals for conditioning	1.55
Total chemicals	9.90

E. HURWITZ

Sewage Plant to Sell Effluent to Railroad for Industrial Use

BY J. E. WHITE

Municipal Sanitation, **4**, 16 (Jan., 1933)

The City of Herington, Kansas, plans to enter into a ten-year contract with the Rock Island Railroad whereby the railroad will purchase for industrial use all the effluent from a contemplated activated-sludge plant. It is expected that the revenue from the sale of the effluent at five cents per thousand gallons delivered to the water treatment tanks of the railroad will pay approximately three-fourths of the fixed charges and operating costs of the sewage treatment plant. E. HURWITZ

One-Man Sewage Plant Operation

BY LEWIS D. SUHR

Municipal Sanitation, **4**, 80 (March, 1933)

The new sewage treatment plant at Woodstock, Illinois, was constructed in 1932. The plant consists of screen channel and grit chamber constructed in duplicate; duplicate rectangular primary settling tanks equipped with Link Belt Straight Line sludge conveyors; seven aeration tanks provided with Simplex Surface Aerators; duplicate rectangular secondary settling tanks with Link Belt Straight Line conveyors; conical bottom sludge digester with Downes floating cover and gas collection apparatus; four sludge drying beds; and a pump house which houses, in addition to the pumps required, the control system, the heating system and a laboratory equipped for routine analysis.

The plant is operated by one man, working from 7 A.M. to 5 P.M. daily. There is no night supervision.

In order to determine the feasibility of operating a plant with little or no supervision the author and a chemist made a study of the plant over a 24-day period. During this period the plant operator continued his normal mode of operation. The B. O. D. and suspended solid reduction was taken as a measure of the plant efficiency. These tests showed a reduction in 5-day B. O. D. from the raw sewage to the plant effluent of 95.8 per cent; suspended solids reduction was 91 per cent. The total power consumption, using seven aeration units half the time and only five the remainder, was 21.55 hp./m. g. E. HURWITZ

Village Sewage Treatment Plant

BY ROLAND G. MCDONALD

Municipal Sanitation, **4**, 152 (May, 1933)

The Imhoff-trickling filter plant of the village of East Rochester, New York, was designed to treat 1.2 m. g. d. At present it is handling about 0.4 m. g. d. dry weather flow and up to 0.9 m. g. d. storm flow.

The plant is located in low marshy ground and for this reason it was necessary to build practically all structures above ground. The heavy structures rest on 35-foot piles.

The sewage is brought to the plant through 16-inch welded steel pipe suspended from concrete towers. It then is discharged into the second story of the operating building and passes through a rack, a 10-ft. Dorr detritor and a 5 × 4-ft. Dorr revolving screen with $^1/_2$ × 2-inch openings. From the screen it flows with two circular settling tanks of the two-story type. Provision is made for collection of gas. The effluent is dosed onto the filter beds. The sludge is drawn onto sand beds and dried. Operating results for 1932 show a reduction in suspended solids of 83 per cent and in 5-day B. O. D. of 86 per cent. The average daily flow was 247,240 gallons. Average daily gas collection was 1786 cu. ft. E. HURWITZ

Consolidating Sewage Disposal in Princeton, New Jersey

ANON.

The American City, **47**, 67–70 (October, 1932)

In order to eliminate nuisance about Princeton and Carnegie Lake and pollution of the water supply of the communities below, the borough of Princeton is undertaking to construct a trunk sewer $12^1/_2$ miles long and

ranging from 10 to 36 inches in diameter, to collect and deliver the sewage, now treated in six small plants, to one central plant for treatment.

The site selected as most advantageous required that all sewage be pumped to it. This will be cared for by a pumping station fitted with one 1 m. g. d., one 2 m. g. d. and one 4.5 m. g. d. electrically driven Fairbanks-Morse pumps. A Buffalo gasoline engine power unit with Fairbanks-Morse generator large enough to generate power to run the entire plant is provided as a standby power unit.

The treatment plant is of the separate sludge digestion-trickling filter type. Sewage is delivered into the control channel of the settling tanks and then through the 45° hopper-bottomed settling tanks. Sludge is removed by gravity to an eight-compartment digestion tank with piping arranged for circulation of sludge through any combination of compartments. The digestion tank is covered with a concrete roof.

The digested sludge is dried in two glass-covered beds. The sludge-bed effluent is discharged with the final settling tank where it is chlorinated.

The effluent from the settling tank is treated on trickling filters.

The influent to the final settling tank is chlorinated. E. HURWITZ

The Baltimore Sewage Treatment Plant and Experimental Work

BY GEORGE E. FUCH

The American City, **48**, 55–7 (March, 1933)

The Baltimore sewage works is located on the west shore of the Black River seven miles from the city. The plant treats between 60 and 65 m. g. d. from a population of approximately 700,000. Sewage is carried to the plant through a 12-ft. sewer and passes first through bar screens and meter house and then into four settling tanks 103 ft. by 420 ft. with a depth varying between 10 to 14 feet. These tanks have a capacity of 30 m. g. d. with a 2-hour detention period. The settled sewage then passes through four revolving fine screens and finally onto the filter beds, of which there are 30 acres. The filter effluent is settled in two tanks 10 ft. deep having an approximate area of 300 sq. ft. each.

The digested sludge is dried on beds and a large quantity of it is disposed of by giving it to truck farmers in the vicinity. Lack of storage space has made it necessary to lagoon a part of the mixed digested and undigested sludge. This practice has worked out satisfactorily since by siphoning off the supernatant liquor and natural evaporation the sludge dried and compacted. One of the lagoons was covered with soil when

full and seeded. The digested sludge from another containing 70 per cent moisture is being carried off by farmers for fertilizer.

Experiments using Genter and Oliver filters for dewatering sludge were conducted. It was found that either type is satisfactory, the cost varying between $4.22 and $5.00 per ton dry solids, depending on the coagulant used. This cost, compared with an average cost of $6.25 per ton for air drying, has made it advisable to install filters as soon as funds are available.

E. HURWITZ

An Unusual Sewage Treatment Plant

BY V. M. VEITCH

The American City, **48**, 54–6 (February, 1933)

The new West End Sewage Treatment plant at London, Ontario, was constructed with no provision for disposal of sludge other than incineration. The plant is an activated-sludge plant having a maximum capacity of 6 m. g. d. Sewage enters the plant through 48-inch and 20-inch sewers and flows consecutively through the grease trap, grit chamber, Hawkins fine screen and aeration tanks, of which there are 24. The sludge disposal problem was solved by mixing the excess sludge with the raw sewage and passing the mixture through the fine screens on the theory that the sludge would adhere to the coarser particles in the sewage and be removed with them. This practice was found satisfactory. The screenings are then pressed in a screw type press and incinerated. It was found that the mass practically supported its own combustion, requiring only a little coal for starting.

E. HURWITZ

A Modern Sewage Treatment Plant in Huron, South Dakota

BY U. F. TURPIN

The American City, **48**, 39–42 (May, 1933)

The sewage treatment plant at Huron receives the waste from a population of 10,000 and from the slaughter house of Armour and Company. This combined waste is concentrated, having a B. O. D. of over 900 p. p. m. and high suspended solid content. The sewage enters the plant through one inch bar screens and then flows into one or all of three grit chambers, each of which is 2 ft. wide by 60 ft. long. From the grit chamber it flows to a primary settling tank 65 ft. square with a 10-ft. side water depth. From the primary tank it is dosed onto a filter bed having an area of 1.3

acres. The filter effluent is discharged into the James River. Sludge is digested in two heated tanks providing capacity for 82,500 cu. ft. of sludge. These tanks are equipped with Dorr sludge removal mechanism and gas collectors. As much as 75,000 cu. ft. gas per day has been produced.

The unit cost of this plant is given as $74,000 per million gallons.

The reduction in B. O. D. is 92.7 per cent. A marked improvement in the condition of the river below the outfall has been noted since the plant went into operation October, 1931. E. HURWITZ

Heating Top Sludge to Produce a More Uniform Rate of Digestion in Heated Sludge Digestion Tanks

BY H. W. TAYLOR

Public Works, **64**, 16–7 and 18 (April, 1933)

Seasonal Sludge Digestion.—A seasonal variation in the digestive activity in a heated digestion tank occurs in spite of the average tank temperature which may be maintained. The effect of cold weather is more pronounced in the northern climates, and the operating data from the separate sludge digestion plant at Saranac Lake, New York, serves to illustrate the wide variations which may occur.

The curves accompanying the article show three distinct variables, namely, outdoor temperature, top sludge temperature and gas production. These factors vary in parallel within certain limitations. With warm weather, the top sludge temperatures are high and gas production is high; while the reverse is true during the colder periods of the year, although the average tank temperature is maintained throughout both periods. The gas production varies in monthly averages during the summer period from 11,100 cubic feet per day to 5332 cubic feet per day during the fall period. The variation on a daily basis was from 15,000 cubic feet per day on July 22, 1932, to 3600 cubic feet on December 18, 1932.

Causes of Variations.—It is agreed that for rapid digestion, other than thermophilic, a temperature of between 80° and 86° must be maintained. These temperatures have been maintained in the body of the tank but have not been maintained in the top sludge. A large volume of the sludge settles to the bottom of the tank and stays there unless overagitated and forms a bottom sludge. Between these two layers of sludge, top and bottom, there occurs the "supernatant liquor." The top sludge contains elements which assist in flotation, such as greases and fats, and these elements contain per unit of volume the greater potentiality for gas production. The top sludge is not successfully heated by the tempera-

tures below it, and warm weather is required before the top sludge can gain sufficient temperature to become active.

The actual temperatures existing in the top sludge of the covered tank were taken on December 23, 1932, with a recording thermometer. These temperatures varied from 36° at the surface to 81° four feet below the surface at the bottom of the top sludge. It is obvious that heated digestion could not take place in this sludge under these conditions.

Although digestion takes place on the return of warm weather, there are many reasons for attempting to rectify these wide variations and provide for a more uniform digestive activity. Excessive rates of gas production are of little value in the summer time, while increased flow of gas is often paramount during the winter months.

Heating Top of Cover.—After various experiments were tried at this plant and two others, it was decided that the solution lay in imitating summer conditions in the cover and that it was necessary to have the temperature conditions in the cover under the control of the operator.

At Saranac Lake the digestion tank is equipped with a Downes cover which has a space between the ceiling plate and the insulated weather roof. This attic space lends itself to hot air heating, and the exhaust burner provides an opportunity to divert waste heat to a useful purpose. A coil was installed around the waste burner and a blower supplies air to the coil and hot air to the cover attic. Owing to the short period during which the heating installation had been in operation, at the time of publication of the article, no striking increase in gas production had been indicated.

C. T. WRIGHT

Salvage of Existing Structures Permits Economical Rehabilitation of Obsolete Sewage Works

BY F. M. VEATCH

Public Works, **64**, 9–10 (April, 1933)

The reconstruction of the 20-year-old septic tank—contact filter plant at Osage City, Kansas, which cost approximately $24,000, was accomplished by the utilization of structurally sound but obsolete existing structures, resulting in a saving of approximately 25 per cent.

The original plant consisted of a three-compartment septic tank and four contact beds. The lack of provision for sludge removal and drying in the original layout was met with a diaphragm pump and an improvised lagoon.

The plan of treatment selected included coarse screening, pre-aeration, settling with separate sludge digestion, sprinkling filter treatment and final settling.

The screen chamber and pre-aeration tank are new and consist of a hand-cleaned rack with 1-inch clear openings and a tank designed to permit a 10-minute contact with diffused air through a grid of Norton porous tubes. The settling tank and sludge digester were formed by fitting one of the compartments of the original septic tank with apparatus for sludge and scum removal, and placing a new cover fitted with gas collection domes over the other two. The settling tank has an average detention period of approximately six hours and the unheated sludge digestion tanks have a capacity of 3.7 cubic feet per capita. The digestion tanks abut the settling tanks and are well insulated with earth fill, thus assuring relatively even temperatures.

The sprinkling filter was formed by adding $2^1/_2$ feet of rock to the existing contact beds, which were $4^1/_2$ feet deep, to form one filter 7 feet deep, which gave an allowance of 15 cubic feet of stone per capita. The sprinkling filter was equipped with a distributor of the traveling crane type, which carries a distributing trough that spans the bed.

A final settling or humus tank has been included, providing a detention period of approximately $1^1/_2$ hours. Sludge drying beds of conventional design and with an allowance of 1 square foot per capita have also been provided.

C. T. WRIGHT

The Association of Managers of Sewage Disposal Works Proceedings, 1931

J. B. CROLL, *Secretary*

1, Main Drainage Works, West Hall Road, Kew Gardens, Surrey

The Flow of Sewage through a Sewage Works in Relation to the Settlement of Suspended Solids. By WILLIAM CLIFFORD.—The wide variations in the quantity and quality of sewage are considered from the standpoint of kinetic energy. Water in motion possesses kinetic energy. A table is given showing the relative kinetic energies at different rates of flow. To stop the motion of water, energy must be dissipated. In a tank, the continual and varying input of energy is one of the disturbing factors in the settlement of suspended solids. Under normal conditions of flow in rectangular tanks having 6 to 8 hours' capacity, the continuous input is dissipated largely in eddies near the inlet end of the tank and in keeping the bulk of the liquid in motion (slow circulation). As the input of energy increases (as is the case with storm-flows, etc.), the whole of the mass is turbulent and only the heavier solids settle out. Difficulty is also encountered if there is not enough energy to effect the mixing sufficient to retain the liquid in the tank for the necessary period of settlement.

Low energy input in a large tank leads to "dead" water and short circuiting. Under most favorable conditions about 80 per cent of the total solids in domestic sewage will settle in 1¾ to 1 hour.

The Influence of Chlorine on an Activated Sludge Process. By H. D. BELL.—Abstracted in THIS JOURNAL, **3,** 320 (1931).

Experiments on the Destruction of the Filter Fly (Psychoda). By W. D. SCOULLER AND A. H. GOLDTHORPE.—Abstracted in THIS JOURNAL, **5,** 185–7 (1933).

Sludge Digestion as Applied at the Chingford Works. By W. HUGHES.—Abstracted in THIS JOURNAL, **3,** 329 (1931).

Some Experiments on the Treating of a Sewage Containing Wool Scouring Refuse. By C. C. BREEDHAM.—Abstracted in THIS JOURNAL, **3,** 336 (1931).

Notes on the Purification of Yeast Waste. By W. F. A. SNOOK.—The cultivation of yeast is as follows: The yeast is grown on molasses, which is mixed with water, at the same time superphosphates are added and some nitrogenized substance, usually an ammonium salt. The superphosphates contain about 45 per cent calcium sulphate, which, with the albuminous material forms a heavy sludge in the mixing tanks. The supernatant liquor from these tanks is run into "cultivation tanks" with the mother yeast, and compressed air is blown into the mixture. The yeast is run from the surface of these tanks into centrifugal separators, where it is separated from any remaining cultivation liquid. It is then washed with water and filter pressed.

Waste liquid from the mixing tanks, cultivation tanks, separators and presses is discharged to the sewers. Samples of these wastes quickly putrefied, generating hydrogen sulphide and showing a separation of colloidal material. The waters are strongly acid. The oxygen consumed (4 hours at room temperature) was 2200 p. p. m., and the suspended matter 16,730 p p. m.

Filters were found to be efficacious in treating these wastes; the oxygen consumed figure being reduced to 7 p. p. m., and the nitrates had been built up to 23 p. p. m.

For treating sewage containing yeast wastes it is recommended to pass the sewage through precipitation tanks, treating with a heavy dose of lime followed by aluminum sulphate and then passing the effluent through trickling filters as slowly as possible. The latter precaution is given so as to reduce the fungus growth which builds up extremely quickly on the filters when yeast waste is present. In the summer the *achorutes viaticus* ate most of this growth and during the rest of the time the application of chlorine in the form of bleaching powder alleviated this difficulty.

Some Methods of Sewage Analysis and Their Use in Works Control. By C. H. HEWITT.—A simple explanation of sewage analyses and their

significance is given. Four methods are given for the quantitative determination of colloidal material: (1) Sample is made strongly alkaline, thereby precipitating the insoluble calcium and magnesium hydroxides and occluding the colloidal material; then adding HCl which forms soluble calcium and magnesium chlorides, the precipitated colloids being filtered and weighed. (2) Sodium acetate and potassium alum are added to the sample and boiled. The colloids are occluded with the aluminum acetate and the precipitate weighed. A blank is run on the reagents alone and the difference in the two values gives the amount of colloidal material. (3) On standing, the bacterial action in the sample will cause most of the colloidal matter to settle. (4) Passage through a semi-permeable membrane.

Hale Sewage Works. By J. E. EVANS.—The plant consists of a preliminary tank, two detritus tanks, a tank for mixing the returned sludge with the incoming sewage, four aeration tanks, a lagoon for sludge digestion and sludge drying beds.

Sewage Disposal at Barnsley. ANON.—*High-Level Works.* The sewage treated is mostly domestic, containing only 7 per cent trade wastes from linen works and a brewery. The plant consists of four detritus tanks; four sedimentation tanks, two of which are operated in parallel; trickling filters; humus tanks and sludge drying beds.

Low-Level Works. At this plant, chlorine in the form of bleaching powder is added to the sewage, which then passes through two detritus tanks; then through two Dortmund tanks for primary settlement; to the aeration tanks and finally to the humus tanks.

Some Considerations in the Oxidation of Sewage. By F. R. O'SHAUGHNESSY.—Abstracted in THIS JOURNAL, **3,** 524 and 748 (1931).

Some Methods and Costs of Oxidizing Sewage. By F. C. VOKES.—The costs of sewage treatment at five plants in the Birmingham Tame and Rea District Drainage Board is presented. The bulk of the sewage is dealt with at the main works in the Tame Valley; the sedimentation and storm water tanks are at Saltley and the activated-sludge plant and bacteria beds are at Minworth. A summarization of costs is as follows:

Plant[a]	Contributing Population	Avg. Flow Treated Imperial, M. g. d.	Oxygen Absorbed, 4 Hrs. (P. p. m.) Settled Sewage	Eff.	Cost per M. g. Treated,[b] £
1	235,000	7.5	95	19.2	5.51
2	375,000	12	95	13.6	4.70
3	470,000	15	95	23.5	4.56
4	125,000	4	95	18.1	5.84
5	100,000	3.18	65	6.5	7.75

[a] Plant No. 1. Minworth Works, bio-flocculation plant No. 1 (diffused air and mechanical aeration) and bacterial beds with fixed spray jets.

Plant No. 2. Minworth Works, bio-flocculation plant No. 2 (air diffusers only) and bacteria beds with rectangular traveling distributors.

Plant No. 3. Minworth Works, bacteria beds with fixed spray jets.
Plant No. 4. Minworth Works, bacteria beds with traveling distributors.
Plant No. 5. Colehall Works, bacteria beds with rectangular traveling distributors.
[b] Does not include the cost of land, establishment charges, cost of maintaining roads, plantation, etc. Interest throughout taken as 4¾ per cent.

The Works of the Birmingham Tame and Rea District Drainage Board. ANON.—This District comprises three works; the main one in the Tame Valley and two works in the Cole Valley.

All of the sewage is alkaline and highly colloidal. Average analyses for the year show it to have a suspended solid content of 470 p. p. m.; 44.4 p. p. m. free ammonia; 200 p. p. m. oxygen absorbed in four hours (unsettled sewage) and 156 p. p. m. (settled) and an alkalinity of 257 p. p. m.

The sewage flows first through a rough screen formed of bulb bars, then into the detritus pit, on through 5 primary sedimentation tanks working in parallel, to 3 secondary tanks also in parallel and then to the bio-flocculation tanks and/or bacteria beds. Effluent from the Saltley works is chlorinated before flowing to the aeration tanks at Minworth.

The sludge from the primary and secondary sedimentation tanks is digested. That from the bio-flocculation units, humus and silt tanks is run into sludge dewatering tanks and then into sludge conditioning tanks where it is aerated.

Southall-Norwood Sewerage and Sewage Disposal. By J. B. THOMSON.—The sewage flow averages 1,900,000 g. p. d. (dry weather). The sewage passes through a revolving screen, 2 detritus tanks, is chemically treated with lime and alumino ferric, then goes to precipitation tanks and then to percolating filters. The sludge from the precipitation tanks is pressed by three filter presses, two 1-ton presses and one ½-ton press. Lime is added to the sludge before pressing. This sludge is sold to farmers. The oxygen absorbed (4 hours) in the crude sewage is 93.6 p. p. m.; in the detritus tank effluent, 86.7 p. p. m.; in the precipitation tank effluent, 45.2 p. p. m.; and in the effluent from the percolating filters, 8.9 p. p. m.

Sewage Disposal Works. By ARTHUR J. MARTIN.—Some notes on the Southall-Norwood plant reiterating the paper by J. B. Thomson.

Some Notes on the Construction of the New Works at the Southall-Norwood Sewage Disposal Works. By R. D'ARCY SWAINSON.

Notes on the Nagpur Sewage Disposal Experiment. By MESSRS. WILLIAMS AND TEMPLE.—This full-scale experimental unit consisted of a septic tank with a capacity of 11,000 gallons; an activated-sludge installation of 4 aeration tanks with a capacity of 4000 gallons each; and a Simplex aerator, capacity 12,000 gallons.

An average of a 6-months period in the septic tank showed a reduction of 70 per cent in oxygen absorption (4 hours). Partial aeration in the

activated-sludge installation gave 95 per cent reduction in oxygen absorption (year's average). Reduction of this figure in the Simplex unit was 81 per cent.

Manchester District, Descriptive Notes. By S. H. MORGAN.—The dry weather flow is approximately 2.5 m. g. d. The sewage enters detritus tanks which are equipped with scum boards to arrest the tar and oil. It then passes through bar screens, thence to sedimentation tanks and on to filters. The effluent goes to humus tanks and from there to 2 pyramidal tanks and on into the river. Sludge is digested, and gas is collected and used for heating the tanks. The gas averages 37 per cent carbon dioxide, 1.1 per cent nitrogen and 61.9 per cent methane. Heating value is 624.

Cheltenham Sewage Purification Works. By J. S. PICKERING.—Abstracted in THIS JOURNAL, **3,** 531 (1931).

Sewage Treatment in America. By E. B. BESSELIEVRE.—General.

Experiments on, and Treatment for the Destruction of the Filter Fly (Psychoda). By W. D. SCOULLER, H. H. GOLDTHORPE AND W. WATSON.—Abstracted in THIS JOURNAL, **4,** 215 (1932).

Some Fundamentals of Sewage Treatment. By J. H. SPENCER.—A review of the principles and definitions.

The Design, Equipment and Operation of Small Sewage Works. By N. S. BOWER.—A review.

The Bio-Chemistry and Analysis of Sewage as Factors in the Determination of the Efficiency of Various Processes of Purification. By GRANVILLE BERRY.—General.

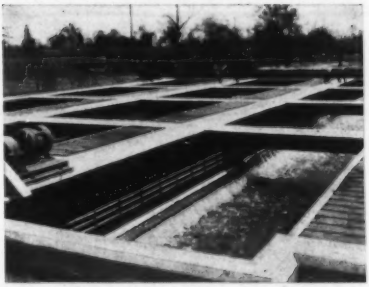
The Admission of Trade Refuse to Sewers. By J. H. GARNER.—Abstracted in THIS JOURNAL, **4,** 380 (1932).

Equalizing the Flow of Gas Liquors Into Sewers. By J. H. GARNER.—This is a description of the Bedford plant. Five thousand gallons per day of spent liquor is produced during 153 days of the year. An equalizing plant was devised to average this discharge over 365 days of the year. The liquor flows by gravitation from the sulphate plant to the settling pit and the first storage tank, and it is then pumped by a steam pump to the second storage tank where it undergoes further settlement. This tank insures a constant feed into the subsequent constant-head tank, into which the liquid passes via a meter which records the daily flow.

H. GLADYS SWOPE

[Short Talks with Sewage Plant Designers]

Sprinkling Filters Cost Lots of Money



THERE are two outstanding factors contributing to the cost of Sprinkling Filter installations:

(1) The price of the land they occupy.

(2) The enormous quantity of broken stone or other material required for the filter medium.

When conditions require a secondary oxidation treatment, why not use the modern activated sludge process served by Link-Belt Straightline aerators? They require no filter medium, or air compressors for providing the one and one-half or two million cubic feet of compressed air for every million gallons of sewage treated.

Straightline aerators installed in tanks with rounded corners and longitudinal baffle produce a spiral circulation and thoroughly mix the contents of the tank while simultaneously and continuously agitating and renewing the surface of the liquid, thereby injecting the oxygen required from the atmosphere. And it is "free oxygen"—always available without the use of compressors, pipes, tanks, etc.

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Link-Belt has spent years developing a form of aerator paddle of high efficiency and annoyance-free operation, as illustrated herewith, and known as the Straightline aerator.

This aerator is a simple, compact, efficient and dependable unit for oxidizing sewage at a minimum of initial and operating cost.

Investigate by competitive estimates, how much less expensive and how much better the Straightline aerator is than other types, particularly for the smaller plant.

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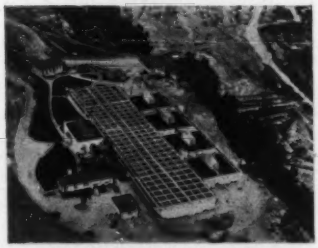

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For Rectangular Tanks

The Hardinge Rectangular Tank Clarifier consists of an automatically operated traveling bridge crane with suspended sludge scraper and skimmer moving continuously back and forth along the length of the tank. It is provided with protective devices against overloads and obstructing materials within the tank. The operating mechanism is not submerged.

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The Hardinge Dome Roof Digester, which uses the Hewett method of prestressing the reinforcing steel, utilizes the full value of the steel, economizes in the amount of material used, and places the concrete in compression. This eliminates cracking of concrete and gas leakage. The digester is attractive in appearance and is equipped with gas dome and sludge and scum dislodging mechanism. Other types include girder or truss flat roof supporting construction.

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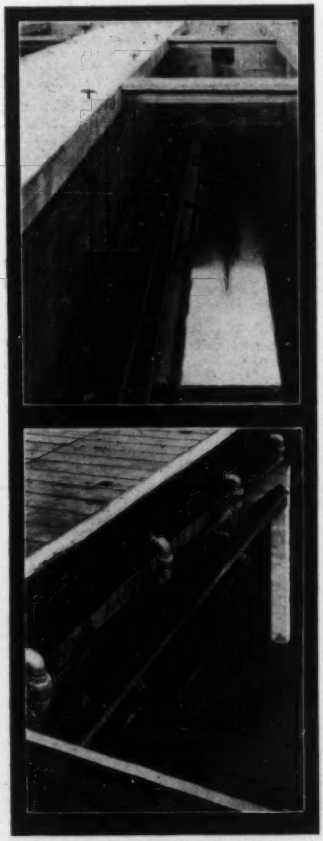

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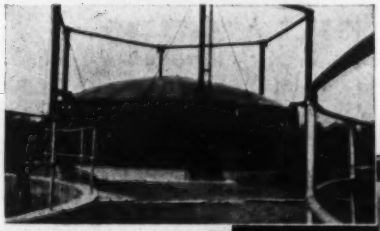

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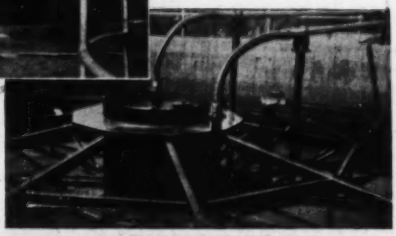
Gas Holder



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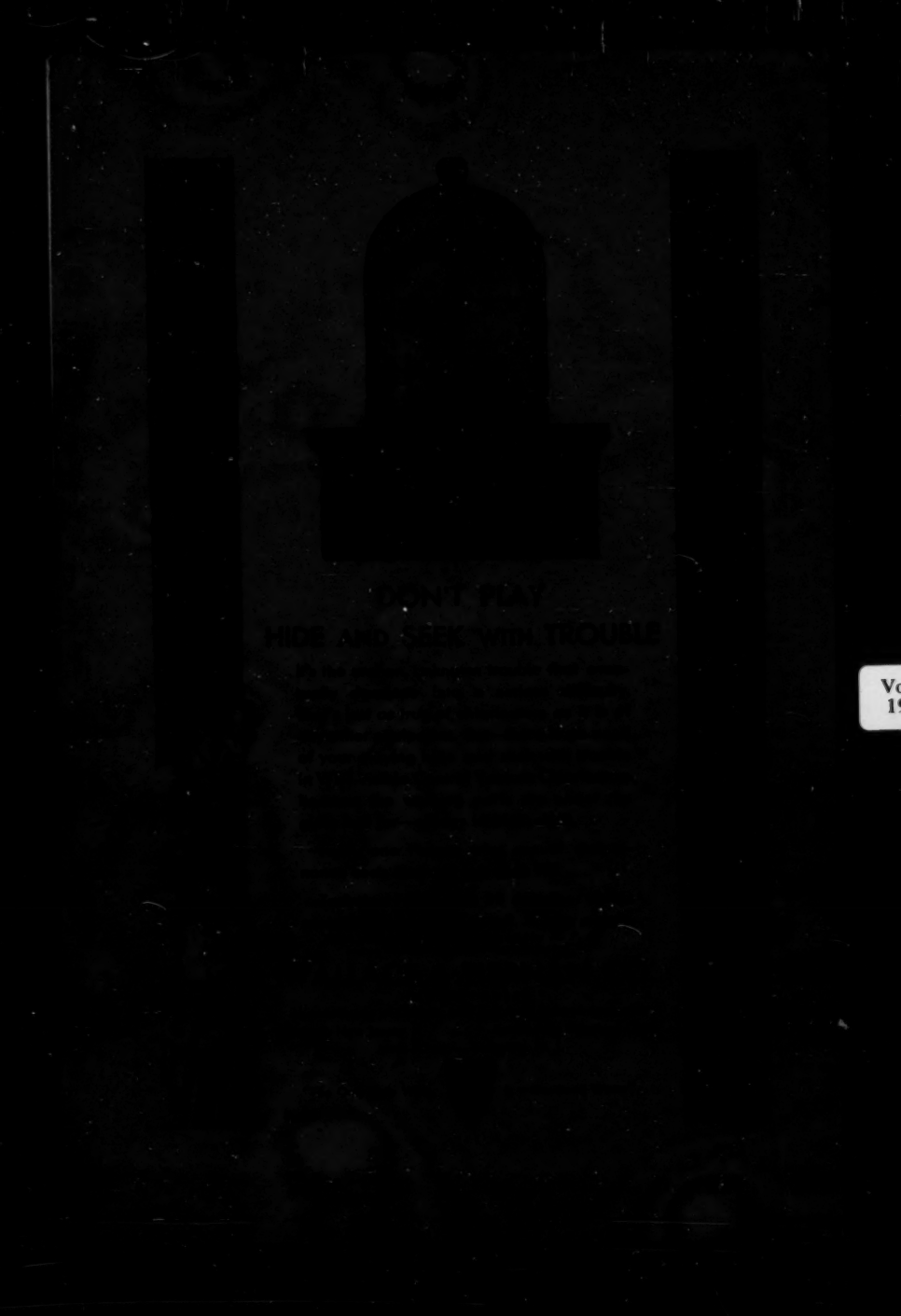
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